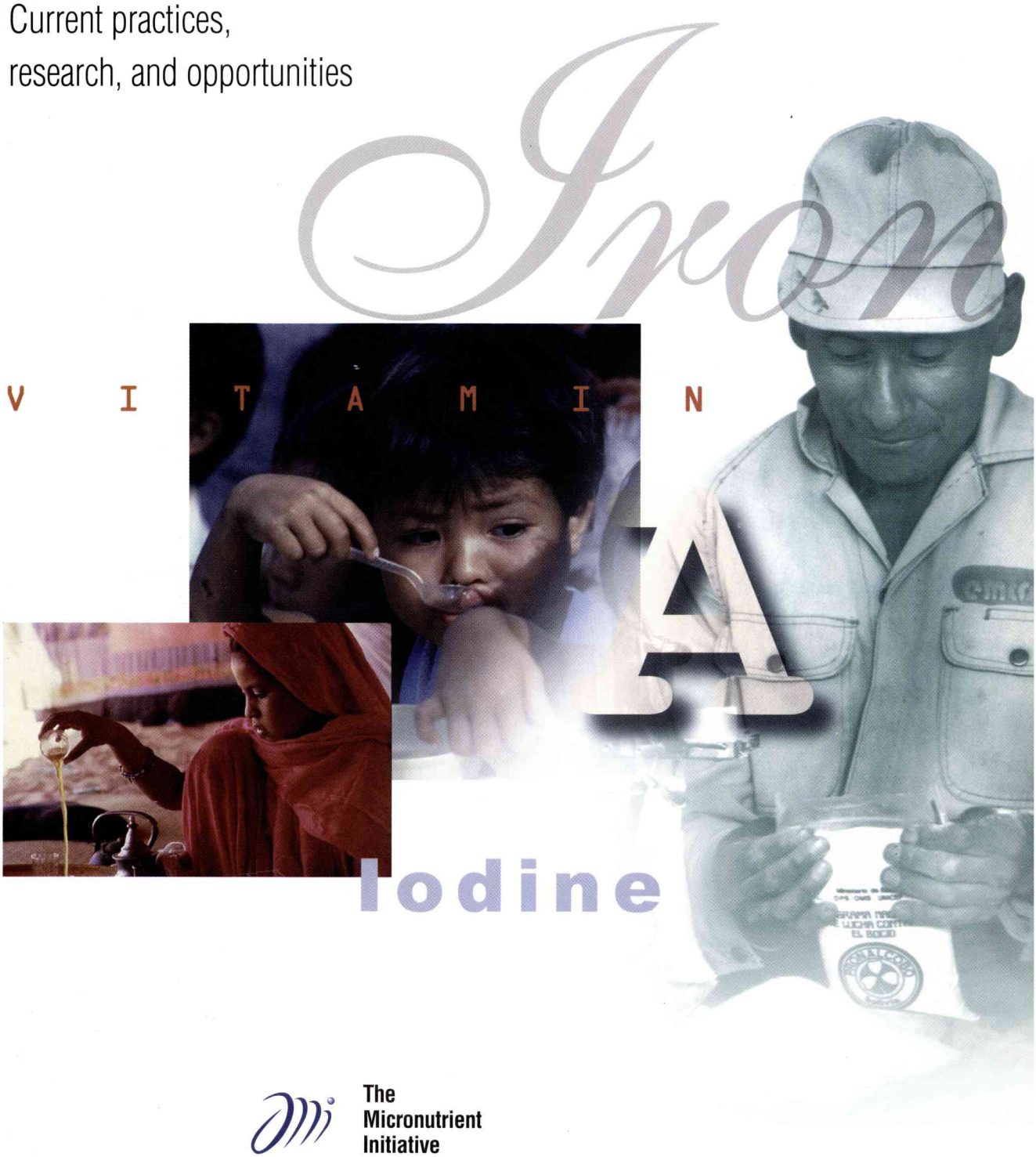
Micronutrient Fortification of Foods

Current practices,
research, and opportunities



The Micronutrient Initiative

International Agricultural Centre

Micronutrient Fortification of Foods

Current practices, research, and opportunities

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CONTENTS

PREFACE

Deficiencies in three micronutrients — iodine, iron, and vitamin A — are widespread affecting more than a third of the world's population. Individuals and families suffer serious consequences including learning disabilities, impaired work capacity, illness, and death. They could waste as much as 5% of gross domestic product (GDP). Addressing them comprehensively, using an array of low-cost solutions, could cost less than 0.3% of GDP. In the words of the World Bank in its recent publication "Enriching Lives" ". . . No other technology offers as large an opportunity to improve lives . . . at such low cost and in such a short time . . . ."

Many national governments at the World Summit for Children set the target to eliminate deficiencies in micronutrients in populations throughout the world by the year 2000. The basic objective of all national micronutrient programs is to ensure that needed micronutrients are available and consumed in adequate amounts by vulnerable populations. Strategies should be appropriate to the need and should use existing delivery systems and available technologies where they serve that need. A combination of interventions involving the promotion of breastfeeding, dietary modification (e.g., improving food availability and increasing food consumption), food fortification, and supplementation may need to be emphasized and implemented.

The fortification of commonly eaten foods with micronutrients is one of the main strategies that can be used to improve micronutrient status. Fortification should be viewed as part of a range of measures that influence the quality of food including improved agricultural practices, improved food processing and storage, and improved consumer education to adopt good food preparation practices.

Today, in developed countries where there is a high dependence on processed foods and industries are streamlined and automated, food fortification has played a major role in the health of these populations over the last 40 years, and several nutritional deficiencies have been eliminated. In the developing countries too, fortification is increasingly recognized as a measure to improve the micronutrient status of large populations. When fortification is imposed on existing food patterns, it may not necessitate changes in the customary diet of the population and will not call for individual compliance. Thus, fortification can often be implemented and sustained over a long period. It can, therefore, be the most cost-effective means of overcoming micronutrient malnutrition.

The food industry is playing an increasingly critical and complex role throughout the world. In the developed countries, changes in living and marketplace patterns have stimulated changes in food industry practices, resulting in a diversity of food-processing technologies and ever-changing numbers and types of foods on the market shelves. As the food industry is increasingly driven by market forces into the global marketplace it is faced with a significantly different scenario. In marked contrast to the developed world, most developing countries are grappling with fundamental issues of providing adequate food supplies to feed their expanding populations.

Simple nutritional and technological solutions to the problems of micronutrient malnutrition exist but are often complicated by economic, social, and political factors. Intervention strategies must take these factors into account. This is the challenge, as well as the opportunity, for the food industry to play a key role in improving the physical, social, and economic well-being of billions of people.

This manual has been prepared to facilitate and encourage large-scale implementation of fortification programs in countries where micronutrient malnutrition is prevalent. It responds to a long-felt need for a comprehensive documentation of technologies and opportunities for fortification.

Given that technologies are in different stages of development and application, an attempt is also made to review critically the status of these technologies and identify the steps involved in refining them for large-scale application. In addition, the manual appraises their technological feasibility, practicability, cost effectiveness, and consumer acceptability. An annotated bibliography on food fortification, containing more than 500 references with abstracts, including the references mentioned in this manual, will be published as a companion volume.

It is hoped that this manual will be a useful reference for national micronutrient program managers and food

industry managers to plan and expand food fortification as a long-term and sustainable solution to the global problem of micronutrient malnutrition.

This document is a product of a unique collaboration between the International Agricultural Centre (IAC) in the Netherlands and the Micronutrient Initiative (MI) in Canada. It has also evolved out of experience gained in organizing the short-term training course in food fortification at the IAC. The authors are grateful to Ms J. Cervinskas (MI), and Ms F. de Boer (IAC) for overall technical review of the document.

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1. INTRODUCTION

THE PROBLEM OF MICRONUTRIENT MALNUTRITION: MAGNITUDE, CONSEQUENCES, AND CAUSES

A significant proportion of the world's population suffers from, or is at risk of, deficiencies of vitamins and minerals, commonly referred to as micronutrients. Adequate intake and availability of these dietary essential vitamins and minerals are closely related to the survival, the physical and mental development, the general good health, and the overall well-being of all individuals and populations.

Vitamin A, iron, and iodine are three major micronutrients attracting much attention, particularly in the last decade. The reasons behind focusing efforts on reducing the deficiencies of these three micronutrients are:

- Based on available information, vitamin A, iodine, and iron deficiency anemia are highly prevalent in the world today;
- Available information points to the serious adverse consequences of these deficiencies for physical and mental health, education, work capacity, and economic efficiency;
- Although some of the obvious clinical consequences of micronutrient malnutrition have been known for a long time, the global dimensions and broad spectrum of detrimental effects of even mild micronutrient deficiencies on physical and mental development, mortality, and morbidity have been recognized only recently;
- The extent of these deficiencies at population and individual levels can be measured relatively accurately; and
- Solutions for eliminating these deficiencies are known, are fairly easy to implement, and are cost effective.

For all three micronutrients, prevalence rates are much higher in developing relative to developed countries. Iron deficiency, however, is so prevalent that even in developed nations the rates among some pregnant women may reach the levels of public health significance.

There have been several studies to identify the extent and severity of micronutrient malnutrition in developing countries. Its distribution is illustrated in Table 1-1.

IODINE DEFICIENCY DISORDERS (IDD)

Iodine deficiency is probably the first nutritional disease recognized by mankind, as both effects of iodine deficiency in the form of goitre and cretinism and its dietary treatment have been known since ancient times. The thyroid gland, requiring iodine for producing its hormones, enlarges in iodine deficiency, making goitre (enlarged thyroid) the best known sign of deficiency. Goitre, however, is only one indicator, and there are many deficiencies that may begin before birth and persist throughout the life cycle. Infants born to iodine-deficient women, if they survive, may be cretins with short life expectancy, physically or mentally retarded, and deaf or mute and spastic, depending on the degree of iodine deficiency. The term iodine deficiency disorders (IDD) has thus been introduced since 1983 to represent this spectrum of physical and mental deficiencies (Hetzel 1983). Iodine deficiency is the most common cause of preventable mental retardation.

Today, roughly 1.6 billion people live in areas where soils lack sufficient iodine. About 655 million people have goitre,

Table 1-1. Population at risk[a] of and affected by micronutrient malnutrition (in millions).

Region[b]	Iodine deficiency disorders (IDD)[c]		Vitamin A deficiency[d]		Iron deficient or anemic[f] population affected
	At risk of IDD	Affected by goitre	Population affected[e]	Prevalence (%)	
Africa	181	86	53	49	206
Americas	168	63	16.1	20	94
Southeast Asia	486	176	126.5	69	616
Eastern Mediterranean	173	93	16.1	22	149
Western Pacific[g]	423	141	42.1	27	1,058
Total	*1,572*	*655*	*254*		*2,150*

[a]Number of persons living in areas at risk of IDD and number of preschool children living in vitamin A deficient areas.
[b]WHO regions.
[c]Source: WHO 1994a.
[d]Reflects estimates only from data available to WHO in 1994 (source: WHO 1995).
[e]Population affected by subclinical, severe, and moderate deficiencies.
[f]Preschool children only (source: WHO 1992, 1994b). [g]Including China.

whereas 43 million are affected by some degree of mental impairment of which 6 million are cretins. More than half of the affected individuals live in China and India.

By far, the major cause of IDD is a low iodine content in the soil and local environment. There are large areas, particularly mountainous and flooded riverines, that are deficient in iodine. The situation is further aggravated by mankind's own misdeeds: deforestation accelerates soil leaching, which, in turn, washes away the iodine from the topsoil. Foods grown and consumed on iodine-deficient soil will not provide enough iodine to the population and livestock in the area. Entire communities can thus be affected by these disorders.

The aetiology of iodine deficiency is different from the other two micronutrient deficiencies in that it mainly results from geological rather than social and economic conditions. The effects of iodine deficiency, however, may worsen when combined with poverty, general malnutrition, poor sanitation, and area remoteness with little contribution of food to the diet from outside an iodine-deficient area.

IRON DEFICIENCY ANEMIA (IDA)

Iron deficiency anemia (IDA) is the world's most prevalent nutritional deficiency making up about half of all the different types of anemias. According to the World Health Organization (WHO), more than 2 billion people are at risk of IDA or are affected by some form of anemia. Almost half of all women and children in developing countries have anemia. Children with IDA suffer impaired mental and physical development. Pregnant women and young children with IDA have a significantly diminished ability to combat infection. IDA in adults causes fatigue and contributes to low work capacity. Moreover, iron deficiency in terms of deficient iron stores in the body can exist without clinical anemia.

Iron is found in animal products such as red meat and in vegetables, grains, and legumes. Red meat provides readily absorbable iron, but iron from plant sources is much less absorbable. Absorption can be enhanced if meat is part of the diet or if foods rich in vitamin C are consumed at the same time. In fact, a major cause of IDA is the low bioavailability of iron in largely cereal- and legume-based diets leading to poor absorption of the iron from diets. In such instances, the iron status of the population can be improved by modification of dietary habits and the application of appropriate food processing techniques.

VITAMIN A DEFICIENCY (VAD)

Vitamin A deficiency has long been identified as a serious and preventable nutritional disease, but the extent to which populations are affected by it and the implications of the effects for survival and health have only been realized more recently. Basic research has conclusively demonstrated the far reaching biological effects of vitamin A deficiency.

VAD begins as a silent, unseen threat that, if untreated, can eventually rob children of their eyesight and their lives. The progressive effects of vitamin A deficiency begin when a child can no longer see in dim light and thus suffers from what is known as "night blindness" or xerophthalmia. As the affliction continues, the eye's conjunctiva and cornea become dry, lesions then appear on the cornea and, in the severest (clinical) form, the cornea simply melts away causing permanent blindness. Although clinical vitamin A deficiency poses a major threat to children's health, those with mild xerophthalmia or subclinical vitamin A deficiency are also at increased risk of suffering from common childhood illnesses found in most developing countries. These include in particular measles, respiratory tract infections, and diarrheal diseases. Children who have adequate vitamin A status or those treated with vitamin A, however, have immune systems that are better equipped to deal with problems associated with diseases like measles.

Vitamin A deficiency exists in more than 60 countries, at a clinical and/or subclinical level. Based on the available data projected to reflect conditions in 1994, the global estimates of the numbers of children 0–4 years of age clinically affected by vitamin A deficiency is 2.8 million, and those severely/moderately subclinically affected is 251 million (WHO 1995). Thus, at least 254 million children of preschool age are "at risk" in terms of their health and survival. VAD is the second largest cause of global blindness next to cataracts.

The major cause of vitamin A deficiency is inadequate dietary intake of the preformed retinol or precursors of vitamin A. Increased vitamin A requirement in certain physiological or pathological conditions, inadequate absorption, or loss of intestinal contents in diarrhea are often contributory factors in establishing vitamin A deficiency.

ELIMINATION OF MICRONUTRIENT MALNUTRITION: AN OPPORTUNITY TO IMPROVE LIVES

Deficiency of essential micronutrients causes learning disabilities, mental retardation, poor health, low work capacity, blindness, and premature death. The adverse effects of micronutrient malnutrition for survival, growth, development, and quality of life through a wide spectrum of specific disorders are now known better than ever before. Together, these disorders represent a loss to the social and economic potential of national societies that no country can stand to afford.

The arguments for accelerating investment in elimination and control of micronutrient malnutrition are compelling. Such investments promote chances for survival, physical and mental health and well-being, productivity, and economic improvement. In fact, according to a World Bank publication (World Bank 1994) "Deficiencies of just vitamin A, iodine, and iron...could waste as much as 5 percent of gross domestic

product (GDP), but addressing them comprehensively and sustainably would cost less than 0.3 percent of GDP."

Global attention to understand better and to control and eliminate micronutrient deficiencies reached a high level when in 1990 specific goals for the elimination and control of micronutrient malnutrition by the year 2000 were adopted by heads of states and governments at the World Summit for Children held in New York. The goals included:

- Virtual elimination of iodine and vitamin A deficiencies, and
- Reduction of iron deficiency in women by one-third of 1990 levels.

This political commitment has been reexamined at various high-level global and regional meetings since 1990. For instance, at the Policy Conference on Hidden Hunger in Montreal in 1991, about 250 representatives from more than 60 governments and major international and bilateral agencies concluded that the World Summit for Children goals were well within reach of the technical and financial means available. The World Declaration on Nutrition proclaimed by ministers of more than 150 United Nations member states at the International Conference on Nutrition in Rome in 1992 also reiterated the commitments to these eminent global nutrition goals.

Subsequent to the commitments made by governments at the World Summit for Children and the International Conference on Nutrition, much groundwork has been done in many countries to accelerate the reduction of micronutrient malnutrition. National programs that draw on the combined resources of government, industry, scientific, and grassroots organizations are being designed and implemented.

As a means to catalyze and facilitate global actions for elimination and control of micronutrient malnutrition, the Micronutrient Initiative was created by its principal sponsors.[1] Although a combination of the main three strategies to overcome micronutrient malnutrition (supplementation with high micronutrient doses, dietary improvement, and food fortification) is encouraged, micronutrient fortification of foods is seen as a sustainable strategy that can often be implemented cost effectively on a large scale to cover deficient populations. Realizing that no other agencies/groups have currently focused their activities in this field, the Initiative has paid particular attention to micronutrient fortification of foods and food items commonly consumed by the Third World population to ensure the realization of the full potential of fortification as a means to control and eliminate micronutrient malnutrition.

GENERAL FEATURES OF INTERVENTIONS AND THEIR APPLICATION

The main intervention strategies against micronutrient malnutrition are:

- Direct supplementation of vulnerable populations or groups with micronutrient supplements,
- Dietary improvement, and
- Fortification of common foods with micronutrients.

These interventions demonstrate two main approaches to the correction of micronutrient deficiency problem: supplementation with pharmacological preparations, which is a medically based intervention; and food fortification/dietary improvement, which uses a food-based approach to solving these deficiencies. In any case, the major aim of all these strategies is to improve the micronutrient status of deficient individuals, communities, and populations.

Supplementation through periodic administration of pharmacological preparations by injections or in the form of capsules or tablets is an effective strategy whereby substantial and almost immediate benefits can be brought to the most at-risk groups. In situations when there is a dinical urgency, micronutrient supplementation is of immense value to saving sight and life. The supplementation strategy is a relatively low-cost measure against micronutrient deficiency. It only improves, however, the micronutrient status of those who received the appropriately administered medical preparations, leaving behind those hard to reach or practically unreachable at-risk groups (those who are probably the most deficient and ill from the effects of the deficiency), as well as other household and community members not targeted to receive any kind of supplementation.

If micronutrient deficiency exists even in a mild form in the community, it can be assumed that it will persist and continue to harm the health and well-being of individuals. Supplementation often requires a large foreign currency input and an elaborate and costly distribution system. Moreover, if the micronutrient supplement has to be administered on a regular basis (as is the case with lower doses of vitamin A preparations), "patient compliance" is a prerequisite for success.

Dietary improvement aims to increase dietary availability, regular access, and consumption of vitamin- and mineral-rich foods in at-risk and micronutrient-deficient groups of populations in developing countries. Such efforts involve changes in dietary behaviour of the targeted population. The strategy is reportedly effective but requires a relatively long time to achieve concrete results.

[1] The Micronutrient Initiative is currently sponsored by the Canadian International Development Agency (CIDA), the International Development Research Centre (IDRC), the United Nations Development Programme (UNDP), the United Nations Children's Fund (UNICEF), and the World Bank.

Fortification of foods with those micronutrients that have been shown to be insufficient in the daily diet has, to a large extent, been responsible for the elimination of vitamin and mineral deficiencies in developed countries such as Canada, Switzerland, the UK and the USA. Fortification of margarine with vitamin D is thought to have eliminated rickets from Britain, Canada, and Northern Europe in the early part of the century. Fortification of refined flour with iron in Sweden and the USA is credited with the dramatic reduction of iron deficiency anemia. Salt iodization, which began in 1922, showed immediate and spectacular results (Bürgi et al. 1990). Commercial food fortification is particularly appealing because, if the right food is selected, high coverage is assured. Table 1-2 summarizes some of the advantages of fortification over high-dose supplementation.

Because of extensive damages to health and well-being caused by micronutrient malnutrition, its elimination by whatever means, should be regarded as a moral duty of governments and international and national agencies and donors. Nevertheless, to encourage policymakers to adopt effective and sustainable measures against micronutrient malnutrition, some attempts have been made to compute the economic and social returns following investments in these areas. An example is given in Table 1-3 where economic returns on investment in food fortification or supplementation programs related to the three micronutrients are compared. Food fortification is considerably more cost effective than supplementation for iodine and iron; however, vitamin A supplementation of children under 5 years of age appears to be more cost effective than a targeted fortification program for this age group.

Table 1-2. Advantages of food fortification over high-dose supplementation.

	Supplementation	*Food fortification*
• Effectiveness and timeframe	• Effective strategy usually for short term	• Effective medium- to long-term measure
• Delivery requirements	• An effective health delivery system	• A suitable food vehicle and organized processing facilities
• Coverage	• Reaches only populations receiving the service	• Reaches all segments of target population
• Compliance	• Requires sustainable motivation of participants	• Does not require intensive cooperation and individual compliance of individual
• Cost of maintenance	• Relatively high financial resources needed	• Low cost compared to supplementation – to maintain the system self-financing in the end
• External resources	• Foreign currency or external support required for obtaining supplements	• Adequate technology that is locally available or can be easily transferred
• Sustainability	• Relates to compliance and existing resources	• Fortificant compounds may need to be imported

Table 1-3. Comparison of returns on nutrition investment in supplementation and food fortification programs (in US$).

	Cost/life saved ($)	*Discounted value ($) of productivity gained/program ($)*	*Cost per disability-adjusted life year gained*
Iodine			
Supplement women of child bearing age	1250	14	19
Supplement all under 60 yrs	4650	6	37
Fortification	*1000*	*28*	*8*
Iron			
Supplement pregnant women only	800	25	13
Fortification	*2000*	*84*	*4*
Vitamin A			
Supplementation targeted only to under 5 yrs	325	22	9
Fortification targeted only to under 5 yrs	*1000*	*7*	*29*

Source: World Bank (1994).

Fortification programs, however, are usually not targeted to any specific age group and are planned to cover all population groups.

The currently underexploited food-based approaches, namely food fortification and dietary improvement, represent the more sustainable, potentially long-lasting strategic measures. The process of elimination of micronutrient malnutrition can, therefore, be accelerated if fortification of appropriate foods with appropriate micronutrients can be included in national programs of those countries in which such micronutrient deficiencies are prevalent.

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2. DEVELOPING A FOOD FORTIFICATION PROGRAM

RATIONALE AND OBJECTIVES

Food fortification is the addition of one or more nutrients to foods. The main objective is to increase the level of consumption of the added nutrients to improve nutritional status of a given population. It should be noted that the primary role of food fortification is *prevention* of deficiency, thereby avoiding the occurrence of disorders that lead to human suffering and socioeconomic disadvantages. Nevertheless, food fortification can also be practiced to eliminate and control dietary deficiencies and their disorders.

To describe the process of nutrient addition to foods, other terms such as *enrichment, nutrification* (Harris 1968), or *restoration* have been used interchangeably, although each may imply a specific course of action. Although *fortification* refers to the addition of nutrients at levels higher than those found in the original or comparable food, *enrichment* usually refers to addition of one or more nutrients to processed foods at levels specified in the international standards of food identity. *Restoration* refers to compensation for nutrient losses during processing, and *nutrification* means making a dietary mixture or a food more nutritious. According to Bauernfeind (1994), the term nutrification is more specific to nutritional sciences, whereas all other terms have originally been borrowed from other disciplines or applications than food use.

The joint Food and Agriculture Organization/World Health Organization (FAO/WHO) Expert Committee on Nutrition (FAO/WHO 1971) considers the term *fortification* to be the most appropriate to describe the process whereby macro- or micronutrients are added to foods commonly eaten to maintain or improve the nutritional quality of individual foods in the total diet of a group, community, or population. It applies primarily to the use of relatively small quantities of added nutrients/micronutrients.

The terms *double fortification* and *multiple fortification* are used when two or more nutrients, respectively, are added to a food or food mixture. The food that carries the nutrient is the *vehicle,* whereas the nutrient added is called the *fortificant.*

Generally speaking, food fortification can be employed for the following purposes:

- To correct a demonstrated dietary deficiency of those nutrient(s) that are added;
- To restore nutrients initially present in significant amounts in a food but lost as a result of food processing and manufacturing;
- To increase the nutritional quality of manufactured food products that are used as the sole source of nourishment, e.g., infant formulas or formulated liquid diets and weaning foods; and
- To ensure nutritional equivalency of manufactured food products substituting other foods, e.g., fortified margarine as a substitute for butter.

The important steps in developing a generic food fortification program are mentioned in Table 2-1on the next page. The generic model is valid for food fortification programs focused on single- as well as multiple-fortified products. Adjustments must be made when designing a specific food fortification program.

In this document, we are dealing with fortification of foods, food items, and food mixtures with only three major micronutrients: iodine, iron, and vitamin A.

IODINE FORTIFICATION

Iodine deficiency results from irreversible geological conditions, therefore, dietary diversification using foods grown in the same deficient soil cannot improve the iodine intake of an individual or a community. Among the strategies for the elimination of IDD, presumably the only feasible, long-term approach is still the fortification of foods with iodine.

Over the past 60 years, several ways of supplementing iodine in the diet have been proposed. A variety of vehicles such as salt, bread, sweets, milk, sugar, and water have been tried. The iodization of salt has become the most commonly accepted method of iodine prophylaxis in most countries of the world because salt is widely and uniformly consumed by all sections of any population. The process is simple and inexpensive. The fortificants commonly used are potassium iodide (KI) and potassium iodate (KIO_3). Iodate is more stable in impure salt subjected to poor packaging and a humid environment. The addition does not change the colour, appearance, or taste of salt. Countries with effective iodized salt programs have shown sustained reductions in IDD prevalence. In hyperendemic areas where immediate action is needed and/or where logistical problems could delay the development of iodization programs, the administration of iodized oil either by injection or orally, is the alternative strategy.

IRON FORTIFICATION

Compared with other strategies used for correcting iron deficiency anemia, iron fortification of the diet is considered by many investigators to be the cheapest strategy to initiate,

Table 2-1. Steps in the development of a food fortification program.

1.	Determine the prevalence of micronutrient deficiency.
2.	Segment the population if prevalence data indicate the need.
3.	Determine the micronutrient intake from a dietary survey.
4.	Obtain consumption data for potential vehicles.
5.	Determine micronutrient availability from the typical diet.
6.	Seek government support (policymakers and legislators).
7.	Seek food industry support.
8.	Assess the status of potential vehicles and the processing industry chain (including raw material supply and product marketing).
9.	Choose the type and amount of micronutrient fortificant or mixes.
10.	Develop the fortification technology.
11.	Perform studies on interactions, potency, stability, storage, and organoleptic quality of the fortified product.
12.	Determine bioavailability of the fortified food.
13.	Conduct field trials to determine efficacy and effectiveness.
14.	Develop standards for the fortified foods.
15.	Define final product and packaging and labelling requirements.
16.	Develop legislation and regulation for mandatory compliance.
17.	Promote campaigns to improve consumer acceptance.

maintain, reach the largest number of people, and guarantee the best long-term approach (Cook and Reuser 1983). Iron fortification does not have the gastro-intestinal side effects that iron supplements often induce. This is a major advantage in terms of consumer acceptability and marketing of iron fortified products.

Targeted iron fortification to those beneficiaries who are most likely to be iron deficient has proven to be a safe and effective strategy to combat IDA (Ballot 1989). The choice of approach is determined by the prevalence and severity of the deficiency (INACG 1977). A critical step in the design of an iron fortification program is the selection of an iron compound that is both acceptable and well absorbable (Cook and Reuser 1983). It should be noted that for pregnant women iron requirements are very high during the last two trimesters of pregnancy. Even where iron fortification programs are in place, these groups need to continue to receive iron supplements in combination with other nutrients such as folic acid. There are a number of fortificants commonly used for iron fortification such as ferrous sulphate, elemental iron, ferric orthophosphate, etc. (see Appendix 2).

VITAMIN A FORTIFICATION

Food fortification with vitamin A holds considerable potential as a tool to alleviate vitamin A deficiency by bridging the gap between dietary intake of vitamin A and requirement. Fortification with vitamin A is a long-term strategy capable of maintaining adequate vitamin A status over time. In Guatemala, fortification of sugar with vitamin A has proved to be more cost effective and sustainable than other strategies that are being employed.

Most vitamins that are produced commercially are chemically identical to those naturally occurring in foods. A fat-soluble vitamin (such as vitamin A) is usually prepared in the form of an oil solution, emulsion or dry, stabilized preparations that can be incorporated into multivitamin–mineral premixes or added directly to food.

The most important commercial forms of vitamin A are vitamin A acetate and vitamin A palmitate. Vitamin A in the form of retinol (the important active compound in such preparations) or carotene (as beta-carotene and beta-apo-8'-carotenal) can be made commercially for addition to foods. These pure chemicals have mainly been added to foods as food improvers and colorants, but foods can also carry them to increase vitamin A intake of the populations consuming these foods. Vehicles such as sugar, fats and oils, salt, tea, cereals, and monosodium glutamate (MSG) have been fortified with vitamin A. For instance, sugar has been fortified with vitamin A in Costa Rica, El Salvador, Guatemala, Honduras, and Panama. Various oils and fats have been selected for fortification with vitamin A.

ROLE OF FOOD INDUSTRY IN FORTIFICATION PROGRAMS

The food industry plays a key role in any food fortification program in any country. Micronutrient deficiencies are public health problems. Many aspects of a food fortification program, however, such as determination of prevalence of deficiencies, selection of an appropriate intervention, calculation of dietary intake levels of micronutrients, and daily consumption of the food vehicle selected or levels of fortificants to be added and even technology development, should be evaluated by the scientific community and health/agriculture authorities and others. The act of fortification of a food vehicle with fortificants, however, is carried out by the private food industry. Unfortu-

nately, in a majority of cases, ministries of health are often not able or willing to exercise control and motivate (private) industry.

At best, linkages between the health and industry/agriculture ministries are usually weak or nonexistent. In such cases, it may be necessary to help formalize an institutional linkage between government and (private) industry such as those proposed in Pakistan and the Philippines. This institutional model is the independent intermediary between governmental institutions and private industry.

In general, however, national governments do not fortify foods themselves. This is the task and responsibility of the (private) food processing enterprises. Government staff should act as advocates, consultants, coordinators, and supervisors to enable the food industry to fortify appropriate foods effectively and profitably.

The food industry can also play a significant role in the relatively long-term food diversifications strategy through providing improved preservation techniques, improved semiprocessed foods, and by promoting consumption of locally available micronutrient-rich foods in the diet or as a food fortificant.

A successful approach to the micronutrient malnutrition problem through micronutrient fortification of food in a country is possible only if the participation of the food industry is incorporated into a national program. The cooperation of the food industry should be sought at a very early stage of program development. Both the promotion and regulative aspects of a fortification program need to be elucidated. The positive incentives will include the profitability of the fortified product. Product prices should be at a level that enables the producer to recover the cost of fortification plus a modest profit and ensure that the consumer can buy a wholesome product for a fair price.

Food fortification also provides the opportunity for the industry to diversify its products range. A positive press coverage or promotion of the fortified product by government could create consumer-demand for the fortified product. Political and financial positive incentives can be offered in the form of tax exemptions; import licenses and loans for equipment and raw materials; initial subsidies to procure fortificants; assistance in developing an in-process quality control system; training of production, administrative, and marketing personnel; training of the wholesale and retail sector; and prohibition of illegal imports. Mandatory compliance can be ensured through legislation and regulations (see Chapter 6).

Specifically, the industry (both national and multinational) needs to:

- Participate from the very beginning in the planning of the national program that will define a feasible fortification strategy;
- Identify mechanisms for collaboration between national governments, food industry and its marketing system, and nongovernmental organizations (NGOs) and donor agencies;
- Assist in the identification of appropriate fortificants and food vehicles;
- Define and develop quality assurance systems; and
- Participate in promotional and educational efforts to reach the target population.

Food technologists work within one or more food chains. They are, therefore, well positioned as sources of information with regard to raw material supply (national or imported), availability of processing equipment and technologies, and the marketing/distribution network for the final products.

The conditions for a successful food fortification program, supported by the food industry and national government, are summarized in Table 2-2. Apart from the food industry and the government, other partners may include consumers, educationists/teachers unions, sport or youth clubs, teacher–parent unions, disabled persons unions, women's organizations, pregnant women's groups, gynaecologists or midwive's unions, pediatrician or ophthalmologist unions, the media, communication services, extension workers, political parties, religious leaders, cultural leaders, members of parliament,

Table 2-2. Conditions necessary for the success of food fortification programs.

- Political support;
- Industry support;
- Adequate application of legislation including external quality control;
- Appropriate fortification level;
- Good bioavailability of the compound;
- No inhibitory effect of the common diet;
- Human resource training at industry and marketing level;
- Consumer acceptability;
- No cultural or other objection against fortified foods;
- Adequate laboratory assessment of micronutrient status;
- Adequate study design or statistical evaluation;
- In case of IDA, absence of parasitism or other nondietary causes of anemia; and
- No constraint regarding procurement of micronutrients.

chambers of commerce, etc. They can all contribute to the creation of demand and/or monitoring of the fortified product and thus to the success of the food fortification program.

Although simple nutritional and technological solutions to the problems of micronutrient malnutrition exist, these are often complicated by economic, social, and political factors. Any intervention strategy must take these factors into account. This is the challenge as well as the opportunity for the food industry. In this endeavour, the food industry can draw upon active support from the other sectors. What is urgently needed is to identify a set of priority actions and initiate a process of continuous dialogue between the various sectors to move quickly toward the implementation of schemes that will permanently eliminate the problems of micronutrient malnutrition.

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3. FOOD VEHICLES AND FORTIFICANTS

Micronutrient fortification of foods commonly consumed by a given population can be a powerful strategy to combat micronutrient deficiencies in a sustainable manner. By selecting the right food ingredient to act as a carrier (food vehicle) of specific micronutrient(s) (fortificant), the need for encouraging individual compliance or changes in the customary diet will be minimized.

SELECTION OF FOOD VEHICLES

There are relevant criteria for selecting a food vehicle related to the following points:

CONSUMPTION

- High proportion of the population covered,
- Regular consumption in relatively constant amounts,
- Minimal variation in consumption pattern between individuals,
- Minimal regional variation in consumption pattern,
- Appropriate serving size to meet a significant part of daily dietary requirement of the micronutrient added,
- Consumption not related to socioeconomic status,
- Low potential for excessive intake (to avoid any probable toxicity),
- No change in consumer acceptability after fortification, and
- No change in quality (in a broad sense) as a result of micronutrient addition.

PROCESSING/STORAGE

- Centralized processing,
- Simple, low-cost technology,
- Good masking qualities (dark colour and strong odour of the vehicle to mask slight changes to original colour or odour),
- High stability and bioavailability of added micronutrient in final product,
- Minimal segregation of the fortificant and vehicle,
- Good stability during storage, and
- No micronutrient interaction.

MARKETING

- Appropriate packaging that will ensure stability,
- Labelling according to prescribed standards, and
- Adequate turnover rate.

Local circumstances are important determinants in selecting a food, or a food accessory item, to act as the carrier for one or more micronutrients (where customary diets of a population only provide suboptimal levels of these essential micronutrients). Vehicle selection should, therefore, be guided by all these factors.

SELECTION OF FORTIFICANTS

General criteria for selection of fortificants are listed in Table 3-1 and opportunities for food fortification in Table 3-2.

Table 3-1. General criteria for selection of fortificants.

- Good bioavailability during normal shelf life of the fortified product;
- No interaction with flavour or colour systems;
- Affordable cost;
- Acceptable colour, solubility, and particle size;
- Free commercial availability of food grade material;
- Available in encapsulated form if required; and
- Feasibility of addition and dispersion through dry blending or spray coating using premixes if required.

The following fortification technologies are already well developed and widely applied:

- Salt fortification technology for iodine
- Vitamin A fortification for oils, fats, sugar, milk, dairy products, RTE cereals
- Iron fortification for flour, RTE cereals, weaning foods, biscuits, bread, milk modifiers
- Multiple fortification of specific products, e.g., milk modifiers, powders, beverage powders, soup flavouring cubes, and paste products

SOURCES OF FORTIFICANTS

IODINE

Iodine production in the world is limited to a few countries. The principal producers/exporters are Chile and Japan. The Central Asian Republics, Turkmenistan and Azerbaijan, are also iodine producers/exporters, although to a far lesser extent.

For iodine deficiency disorder (IDD) control programs, iodine is usually imported in the form of potassium iodate (KIO_3). If the country requirement is large (>30 tons/year), it will be cheaper to import elemental iodine and convert it to KIO_3. There are suppliers of potassium iodate in France, Germany, India, the Netherlands, and the UK (see Appendix 1).

Table 3-2. Opportunities for food fortification.

	Vitamins									Minerals		
Food	β-Carotene	A	D	E	B1	B2	B6	C	Folic Acid and B12	Fe	Ca	I
Milk:												
Liquid	+	+	+	+	+	+	+	+	+	0	+	+
Powder	+	+	+	+	+	+	+	+	+	+	+	+
With Cereal	+	+	+	+	+	+	+	+	+	+	+	+
Flours:												
Wheat	0	+	+	+	+	+	+	x	+	+	+	+
Corn	0	+	+	+	+	+	+	0	+	+	+	+
Rice	0	+	+	+	+	+	+	+	+	+	+	+
Rice	0	+	+	+	+	+	+	+	+	+	+	0
Snacks	0	+	+	+	+	+	+	+	+	+	+	0
Corn Flakes	0	+	+	+	+	+	+	+	+	+	+	0
Oil	+	+	+	+	x	x	x	0	0	0	0	x
Margarine	+	+	+	+	0	0	0	0	0	x	0	x
Mayonnaise	+	+	+	+	0	0	0	0	0	x	0	x
Juices	+	0	0	+	+	+	+	+	+	+	+	0
Sugar	x	+	0	0	x	x	x	x	0	+	0	+
Powder Beverages	0	+	+	+	+	+	+	+	+	+	0	+
Salt	x	0	x	x	x	x	x	x	x	+	+	+

+ = Possible, o = Trials needed, x = Not possible, Fe = iron, Ca = calcium, I = iodine.

IRON

When choosing an iron source to fortify a food product, one has to consider the influence of the added iron on the organoleptic properties of the product, whether the iron source is likely to be sufficiently bioavailable, whether segregation occurs during mixing or storage, and the cost of the food fortification process. The two principal groups of compounds are haem iron compounds and nonhaem iron compounds, depending upon their sources.

Haem iron compounds are a by-product of bovine slaughterhouses. Haem iron is a very attractive fortificant of foods of vegetable origin. Inhibitors of nonhaem iron compounds in vegetable foods do not interfere with haem iron. Haem iron, however, does affect the fortified product organoleptically and is not suitable for fortification of many products. A successful fortification application has been the Chilean bovine-haemoglobin-fortified cookies program (Walter 1993; see also Chapter 7).

The nonhaem iron compounds can be divided into elemental iron and nonelemental iron. Commercially available iron compounds are listed in Appendix 2 (INACG 1990). The four principal iron sources that have had widespread use in food fortification are elemental iron, ferrous sulphate, ferric orthophosphate, and sodium ferric pyrophosphate (see Appendix 2 on commercially available iron compounds). Ferrous fumarate, ferrous gluconate, and ferrous sulphate are commonly used in mineral supplements (Lee 1979). Sodium ferric ethylenediamine-tetraacetic acid ($NaFe^{(III)}EDTA$) is the only nonhaem iron compound that has a good bioavailability (mean bioavailability of approximately 10%) that is relatively independent of meal composition. It withstands the inhibitory effects of phytates, a component of the staples foods like cereals and grain legumes (Lamparelli 1987).

The status of NaFeEDTA as a recognized food additive is not yet clear. The Joint FAO/WHO Expert Committee on Food Additives (JECFA 1993) has reached the conclusion that NaFeEDTA is safe when used in supervised food fortification programs in iron-deficient populations and has given provisional approval for its use. Pharmaceutical grade NaFeEDTA is rather expensive. A very promising alternative is the use of Na_2EDTA and $FeSO_4$ (in the molar ratio of EDTA to iron between 1.0 and 0.25) in meals with low iron availability. The cost of food fortification with NaFeEDTA as a food additive may be reduced with the alternative fortification mixture Na_2EDTA plus $FeSO_4$ (INACG 1993). Also, a less pure grade (>97%) used in the agricultural industry as a fortificant is commercially available at less than half the cost of the pharmaceutical NaFeEDTA (Ballot et al. 1989).

VITAMIN A

Preformed vitamin A or retinol is found in foods of animal origin, whereas green leafy and yellow vegetables and fruits are rich sources of carotenoids, such as beta-carotene, which is a provitamin A (i.e., the human body is capable of converting it into vitamin A). Some common sources of retinol are mother's milk, liver, eggs, butter, and whole cow's milk. Examples of carotenoid sources are green leafy vegetables, carrots, yams and squashes, mango, papaya, and plantain. Red palm oil is naturally rich in beta-carotene. In processing crude oil to remove undesirable colour and odour, most of carotene is lost. Recent new technologies, however, tend to retain carotene during the refining process (UNU 1994).

Both retinol and carotenes are commercially produced (Bauernfeind et al. 1986; Klaeui et al. 1981). The major commercially available vitamin A products and carotenoid precursors are listed in Appendix 3. Equivalency between retinyl palmitate and beta-carotene for controlling vitamin A deficiency was studied in Senegal (Carlier et al. 1993). It was concluded that beta-carotene supplementation was a promising candidate for the alleviation of vitamin A deficiency. A workshop on bioavailability and bioconversion of carotenoids, sponsored by the MI and USAID in 1995, concluded that carotenoid-rich fruits and vegetables provide a substantial and necessary contribution to the requirements of vitamin A and some other nutrients of the population at risk of deficiencies of such nutrients. Although the consumption of these valuable sources of micronutrients should be promoted, factors that influence their bioavailability and bioconversion need to be more clearly elucidated and studied.

STABILITY AND INTERACTIONS IN THE DIET

The stability of the fortificant in the fortified food or the meal is highly dependent on the chosen compound, the processing conditions, the characteristics of the food, transport and storage conditions, and food preparation and storage habits of the consumer. A field trial, therefore, to establish the impact of the fortified food on micronutrient malnutrition and consumer acceptability is a prerequisite for a food fortification program. Although knowledge regarding vitamin/mineral interactions is limited, it is evident that such interactions reduce impact on nutritional status (Lonnerdal 1986). Some information on stability and interactions of the micronutrient sources is given in the following.

IODINE

Iodine is normally introduced as the iodide or iodate of potassium, calcium, or sodium. Potassium iodide (KI) is the least expensive but most unstable compound. It can easily be lost if the iodized salt is subjected to moist conditions, excessive aeration, sunlight, heat, relatively high acidity, or the presence of impurities in the salt. The adverse effects on potassium iodide caused by oxidation can be reduced by the addition of stabilizers like sodium thiosulphate and calcium hydroxide and/or drying agents such as magnesium or calcium carbonate.

In most cases, however, potassium iodate (KIO_3) is the preferred compound. It is resistant to oxidation and does not require the addition of stabilizers. KIO_3 is less soluble than KI and it is less likely to migrate out of the bag. Calcium iodate has also been shown to be stable in impure salts, but its use in edible salt has not been widespread so far (Bauernfeind 1991).

IRON

In general, the solubility of the iron compounds is inversely related to the duration of storage. The more soluble the compound, the greater its chemical reactivity, and the higher the risk of rancidity. Although ferrous sulphate is the most suitable iron compound from the point of view of bioavailability and cost, it is unstable. The addition of stabilizers proved to give acceptable results without deterioration of the iron availability (Suwanik et al. 1980).

Ferric phosphate and other insoluble iron compounds are stable, but the iron absorption is unacceptably low, particularly when ingested with food. The use of absorption promoters can improve bioavailability without deterioration of the keeping quality (Rao et al. 1975).

Ascorbic acid is a powerful enhancer of nonhaem iron absorption and can reverse the inhibiting effect of tannins. High costs and instability during food storage are the major obstacles to using ascorbic acid in programs to combat iron deficiency anemia (IDA) (Lynch and Cook 1980). There is evidence that vitamin C also has a postabsorptive role on iron metabolism (Anon. 1987). A number of studies (Hodges et al. 1978; Reddy 1985; and others) reported that vitamin A deficiency might in some way be responsible in causing anemia in man, reversible by iron only when vitamin A is administered (ACC/SCN 1987). More recently, Mejia et al. (1992) suggested that there is an interrelationship between vitamin A and iron nutrition. Improving vitamin A nutrition of underprivileged children living in developing countries has a positive effect on their iron status.

VITAMIN A

Pure vitamin A and carotenoid structures are fairly stable when heated to a modest temperature, in an inert atmosphere and in the dark, but are unstable in the presence of oxygen or air or when exposed to ultraviolet light. Vitamin A is quite stable in an alkaline environment. The food fortification industry has developed vitamin A and carotenoid structures with addition of antioxidants as stabilizing agents (Bauernfeind et al. 1986; Klaeui et al. 1981).

Tests in Brazil have shown that vitamin A palmitate added to soybean oil was stable (99% retention) for up to 9 months of storage in sealed metal cans. Cooking trials involving cooking

rice and beans with fortified soybean oil indicated that retention of vitamin A in cooked rice was 99% and in beans it was 88% when cooked by boiling for 90 minutes and 90% when cooked under pressure. Trials with oil for frying potatoes under repeated conditions of deep frying at 170°C and storage indicated that, although there was a progressive loss with repeated frying, 58% of the vitamin A was still retained after four repeated fryings of potatoes in the same oil.

COST OF FOOD FORTIFICATION

The cost of fortification varies over a wide range depending on the vehicle and the fortificant to be added. Vitamin–mineral premixes are now utilized by manufacturers for uniform addition to foods and to reduce control costs. Certain typical values to indicate the order of magnitude are given in Table 3-3 (Mannar 1993).

These are only approximate costs and indicate the order of magnitude figures for actual processing and chemical costs at source. They exclude costs related to program management and product promotion/marketing and monitoring. Often the extra cost at source when passed on to the consumer tends to get magnified at the various stages of distribution because the margins at every level will also increase proportionately. The ultimate cost to the consumer, therefore, will be progressively inflated as the food passes from producer to retailer. This is again an economic question that may need investigation on a case-by-case basis. Another major source of cost is incurred in controlling the levels added to ensure consistency with the label declaration (Clydesdale 1991, p. 95), although this cost is lowered if analytical equipment, personnel, and expertise are available. At least a part of the cost increase related to fortifica-

Table 3-3. Dosage and approximate cost of fortification.

Vehicle	*Fortificant*	*Dosage*	*Cost (range) per person/year in US cents*	*Country*
Salt	K-iodate	50–80 ppm I_2	2–6 (1992)	Several[a]
	Fe(II)sulphate + Na-acid pyrophosphate + Na-acid sulphate	1,000 ppm Fe + 2,500 ppm + 5,000 ppm	12–18 (1991)	India +
	K-iodide + Fe(II)fumarate	50 ppm I_2 + 1,000 ppm Fe	12–20 (1990)	India ++
	K-iodate + Fe(II)sulphate + Na-polyphosphate	20 ppm I_2 + 1,000 ppm Fe + 1% Na-polyphosphate	12–20 (1992)	India[a]
Sugar	Vitamin A 250 CWS	15,000 IU/Kg	29 (1994)	Guatemala[a]
	NaFeEDTA	1.3% Fe	10 (1981)	Guatemala ++
Wheat flour	Elemental iron	25–35 ppm	1.5 (1980)	Several[a]
Cooking fat	Vitamin A	50,000 IU/Kg	30–40 (1988)	Several[a]
Biscuits	Haem iron concentrate	1.8 g Hb/30 g	108 (1981)	Chile +
Edible oil	Vitamin A	20 IU/g	n/a	Pakistan[a]
Margarine	Vitamin A	375 RE/15g	20 (1994)	Philippines[a]
Fish sauce	NaFeEDTA	1 mg Fe/ml	5–15 (1970)	Thailand ++
Monosodium glutamate (MSG)	Vit A Palmitate 250 CWS	175,000 IU/kg	6 (1988)	Indonesia +
Cornflour/ Wheatflour	Iron Vitamin A (plus Niacin, Thaimine, and Riboflavin)	20–50 mg/kg 39,000 IU/kg	7–8 (1994)	Venezuela[a]

[a]Commercial scale; + = pilot; ++ = laboratory scale; n/a = not available.

tion should initially be subsidized (as funding for a nutrition intervention). Gradually, the entire cost could be passed on to the consumer.

BIOAVAILABILITY AND BIOCONVERSION OF MICRONUTRIENTS

The term bioavailability generally refers to the extent to which a nutrient is capable of being absorbed (i.e., enters the blood system) to be utilized within the body. The proportion of a nutrient that can be absorbed is largely related to the functions of the digestive system, the form in which the nutrient is ingested and its concentration (i.e., whether it is present in physiological or pharmacological doses), the composition of the food vehicle and its intestinal motility and other dietary components, or even certain drugs taken concurrently. Other factors may include the health and physiological status of the individual who consumed the nutrient in question. For example, factors such as gastrointestinal motility, the immaturity of intestinal functions in infants, or changes in the efficiency of absorption that occur with age may influence the bioavailability of nutrients ingested.

Other constituents of the foods or the meal, or both, can modify the absorption process. Interactions between components of a dietary mixture within the intestinal contents can either inhibit or enhance transport of the nutrient through the mucosa. For instance, excessive intakes of certain forms of calcium can decrease iron absorption. This, however, is thought to be due to competition at the intestinal absorption site rather than to food interactions. In addition to the interactions between dietary components, therefore, interactions between the dietary components and the intestinal mucosa transport system may occur. According to Clydesdale (1989), it is not only essential to know the major physical and chemical properties that affect bioavailability but also to understand how these may be influenced by food composition, processing, and storage conditions.

Some transport systems are controlled by the nutritional status of the person consuming the diet. Iron status, for example, is decisive for the absorption of iron. When iron status is low, iron absorption is enhanced and when iron status is within normal ranges, iron absorption is restricted. This form of individual physical control is limiting the development of predictive equations and "rules of the thumb" that are practical in the food fortification field.

The concept of bioavailability is central to one of the key goals of the nutritional sciences, i.e., the relationship between the composition of the diet and the nutritional responses to the diet by the organism (see Southgate et al. 1989). Micronutrient malnutrition, especially IDA, may occur as a result of a low bioavailability/bioconversion of the micronutrient in its dietary and physiological setting. IDA may even occur in cases where ingestion is well in excess of physiological requirements. Knowledge of the bioavailability of a nutrient in its dietary setting provides an important section of data that are necessary for establishing dietary requirements for nutrients.

The three factors involved in determining the bioavailability of a food, meal, or diet are:

- Availability in the intestinal lumen for absorption;
- Absorption or retention in the body, or both; and
- Utilization in the body.

Of these factors, utilization of the nutrient in the body is the central feature. The degree of utilization in the body depends on physiological factors and on the nutritional status of the organism.

Bioavailability criteria of a nutrient are:

- The nutrient must be present in a form that can either be transported directly through the intestinal mucosa, or the ingested nutrient must be convertible into a form that can be transported through the intestinal mucosa; and
- The absorbed form must be capable of being metabolized, or the absorbed form must be capable of participating in metabolism.

The bioavailability of a nutrient in the diet is thus a function of:

- The form in which the nutrient is ingested;
- The extent of conversion to absorbable forms;
- The composition of the diet, including concurrent ingestion of certain drugs; and
- The physiological status of the organism and function of the digestive system.

In any food fortification program, the bioavailability of a nutrient in its dietary context, the food consumption data of the target population, and the prevalence rate of those nutrient deficiencies to be controlled/eliminated by the planned food fortification program are among some of the major determinants of the level of vehicle fortification. It should, therefore, be noted that it is the total diet (or meal), and not the nutrient per se, that significantly influences the bioavailability of the separate nutrients.

BIOAVAILABILITY OF IODINE

Inorganic iodide is readily and completely absorbed from the gastrointestinal tract and mostly stored in the thyroid gland. Excess iodine is readily excreted by the kidney. Other forms of iodine are reduced to iodide before absorption (Pennington 1988). Goitrogens such as thiacyanates can block the uptake of iodine by the thyroid gland.

BIOAVAILABILITY OF IRON

The iron in the diet may be present as haem iron (from animal foods) or nonhaem iron (from foods of plant origin). In the

intestine, these two forms are absorbed by different mechanisms. Because haem iron is more easily absorbed from the diet than nonhaem iron, its bioavailability is higher than that of nonhaem iron. As a general rule, scientists assume that 25% of the haem iron from the diet is available for utilization by the human body. This factor of 25% is fairly constant and irrespective of other substances in the diet.

Generally, the bioavailability of nonhaem iron is much lower and also much more variable. Table 3-4 shows major iron compounds used in food fortification and their relative bioavailability and cost.

If provided within the same meal, the following substances will improve the absorption of nonhaem iron: meat, amino acids, vitamin C, and EDTA. The absorption level, however, never reaches that of haem iron. Tannins (tea), phytates (legumes and cereal bran), oxalates, and calcium are dietary substances that inhibit the absorption of nonhaem iron from the same meal. Bioavailability of elemental iron powder increases as particle size decreases. The assessment of bioavailability of iron from a diet is, thus, a complex issue that needs particular attention when decisions are made on the appropriate vehicle, fortificant, and level of food fortification with iron.

BIOAVAILABILITY OF VITAMIN A AND CAROTENOIDS

If provided within the same meal, fat and proteins will improve the bioavailability of vitamin A. Vitamin A deficiency is often associated with protein or protein–calorie malnutrition. Dietary fibre reduces the bioavailability of vitamin A if consumed within the same meal. The bioavailability of carotenoids is also dependent on the level and type of fat in the meal. The actual bioavailability of carotenoids can be as low as 1%. Mild cooking can enhance the bioavailability by releasing the free carotenoids from the carotenoid–protein complexes in green leafy vegetables, but overcooking can destroy any positive effect (Fairweather-Tait 1993).

Table 3-4. Major iron compounds used in food fortification.

Iron compound	*Relative bioavailability in man*[a]	*Relative cost*[a]
Water-soluble		
Ferrous sulphate	100	1
Ferrous gluconate	89	5
Ferric ammonium citrate	n/a	5
Ferrous ammonium sulphate	n/a	2
Poorly water-soluble		
Ferrous succinate	92	4
Ferrous fumarate	100	1
Ferric saccharate	75	4
Water-soluble		
Ferric orthophosphate	31	4
Ferric pyrophosphate	39	4
Elemental iron	13-90	
Experimental		
Sodium iron EDTA	Depends on food vehicle	10
Bovine haemoglobin	n/a[b]	n/a

[a] Both bioavailability and cost are expressed as a percentage relative to that of FeSO4*7H2O.
[b] n/a= not available.
Source: Adapted from Hurrell and Cook (1990, p. 57).

LEVEL OF FORTIFICATION

There is no universal specification for the level of fortification of the chosen food vehicle. Numerous factors influence the recommended level of fortification and the practical amounts used should be decided by the appropriate nutrition authorities, based on sound nutritional surveys. The main determinants of the fortification level are:

- Recommended dietary intake (RDI) of the micronutrient;
- Prevalence of the micronutrient deficiency;
- Percaput consumption of the food vehicle;
- Extent of processing, transit, storage, and food preparation losses;
- Current dietary habits of the population in question with regard to food selection and preparation; and
- Other dietary ingredients affecting its absorption and bioavailablity.

IODINE

The RDI of iodine varies from 150 to 200 µg/day. The basic RDI for adults of both sexes is set at 150 µg/day. An increment over the basic level of 25 µg/day in the RDI is recommended during pregnancy, and an increase of 50 µg/day is recommended for lactating women (NAS 1989).

Current levels of iodization in different countries vary between 20 and 100 ppm iodine (35–165 ppm intake). In a given country, the level of fortification may be changed over time, in response to changes in average daily consumption of salt and iodine losses during distribution and storage. A sample calculation for fixing the level of iodization in salt is given in Chapter 7 (Table 7-1).

IRON

The RDI of iron varies by age and physiological group and depends on the iron bioavailability in the diet (Table 3-5). Menstruating women and teenage girls require the highest iron intake (40–48 mg/day), whereas the requirements for iron in young children in the age of 1–6 years are the lowest (12–14 mg/day), assuming a low iron availability of 5%. For foods with a high iron availability (15%) these figures should be lowered by a factor of 3 (FAO/WHO 1988).

Pregnant women need a total of 1,000 mg iron during a normal pregnancy. This need for iron is not equally distributed

Table 3-5. Recommended dietary intake (RDI) for iron (mg/day).

Iron availability in diet	Low (5%)	Medium (10%)	High (15%)
Adults			
Men (>16 years)	23	11	8
Women (menstruating)	**48**	**24**	**16**
Women (postmenopausal)	19	9	6
Women (lactating)	26	13	9
Children (age in years)			
0.25 – 1	21	11	7
1 – 2	12	6	4
2 – 6	14	7	5
6 – 12	23	12	8
12 – 16 (boys)	36	18	12
12 – 16 (girls)	**40**	**20**	**13**

Source: Adapted from FAO/WHO (1988).

over the duration of the pregnancy but varies from 0.8 mg/day in the first trimester to 6.3 mg/day in the third trimester. Even if the food consumed by a pregnant woman has iron with a high bioavailability, the diet alone cannot satisfy this extra requirement. Administration of supplements may be indicated.

No sample calculation for the amount of iron to be added to a vehicle can be given because the amount to be added depends on the estimated bioavailability (see this chapter under "Sources of Fortificants" and Appendix 4 for premixes).

VITAMIN A

As shown in Table 3-6, lactating women require the highest vitamin A intake. According to FAO/WHO (1988), the safe intake level is a factor 2 higher than the critical intake level. Critical intake level for lactating women is 1,415 IU, whereas for children aged 0–10 years it is 585–670 IU.

There are variations in the consumption patterns of different social and economic groups considering age and physiological status. The appropriate level of fortification should be based on consumption data for the food vehicle chosen for fortification by different socioeconomic and physiological groups in the population. An example is vitamin A and vitamin A precursor levels in margarine, 33,000 IU – ß carotene (as colorant), 10,000–12,000 IU – the remainder to be supplied by added vitamin A ester.

TOXICITY CONSIDERATIONS

SAFETY INDEX

The Swiss medical scientist Theophrastus Bombastus von Hohenheim, better known as Paracelsus (1493–1541) stated: *"Alle Dinge sind Gifft.... allein die Dose macht das ein Ding kein Gifft ist"* ("Everything is toxic... it is the dose which makes an item non-toxic.") This statement is still valid today. If a food fortification program is properly designed and implemented and the level of the micronutrient added is carefully evaluated, there should be no reason for concerns over the possibility of toxic effects of the added minerals and/or vitamins. The benefits of a food fortification program clearly far outweigh any adverse effects (FAO/WHO 1988). Documented toxic effects have been few and transient. Every food fortification program should balance its beneficial aspects against the toxicological risks, which are very limited for iodine, iron, and vitamin A.

Table 3-6. Estimated requirements for vitamin A (µg retinol equivalent per day).

	Basal requirement RE	(IU)	Safe intake level RE	(IU)
Children				
0–1	180	(600)	350	(1,165)
1–6	200	(665)	400	(1,330)
6–10	250	(835)	400	(1,330)
10–12	300	(1,000)	500	(1,665)
12–15	350	(1,165)	600	(2,000)
15–18 boys	400	(1,330)	600	(2,000)
15–18 girls	330	(1,100)	500	(1,665)
Adults				
Men	300	(1,000)	600	(2,000)
Women	270	(900)	500	(1,665)
Pregnant women	370	(1,230)	600	(2,000)
Lactating women	450	(1,500)	850	(2,830)

Note: RE (retinol equivalent) = 3.33 IU (international unit vitamin A activity from retinol).
Source: FAO/WHO (1988).

It is the responsibility of the nutritionists/toxicologists on the program staff to determine the safe fortification levels of a micronutrient in the dietary setting. Anyone involved in a food fortification program, however, should be aware of the toxicological aspects of the fortificant. Apart from the dose, the exposure period is another important factor when evaluating the toxicity aspects of fortification programs.

The safety of any ingested substance can de distinguished according to the following factors (Marks 1989):

- The number of doses and the time interval between them,
- The health status of the person (main indicators are age, pregnancy, and vitamin/mineral status),

- Interference by food or food components (like alcohol) and pharmaceutical (or other) drugs, and
- The mode of administration (oral or parenteral).

In general, for vitamins and minerals that have a large RDI, there is little concern about toxicity from individual foods, except if a large spectrum of foods pertaining to an individual's diet were to be fortified with the same micronutrient. But a well-designed food fortification program should be based on sound nutritional survey data, taking into consideration in its design the total diet of the target population.

Fortification with iodine, iron, and vitamin A is considered to be safe, provided the fortification level does not exceed the RDI level of the micronutrient in the total diet. Table 3-7 gives the safety indexes for the three micronutrients.

The important question to be considered when attempting to define toxic thresholds is the characteristics of the target population of a food fortification program. The fortification level of a food has to be fixed to a concentration of the micronutrient well below the toxic threshold level for normal individuals. *It is essentially a policy matter to make a decision regarding what proportion of the population should be considered normal when setting acceptable, safe intake levels.* If the target population includes individuals or groups of individuals who might be more susceptible to the toxicity of the nutrient than the general population safeguards, measures to protect these individuals at risk should be incorporated into the food fortification program.

IODINE

In general, iodine fortification at levels of up to 200 µg/day does not give rise to any concerns for toxicity. Iodine intakes of up to 2 mg/day have caused no adverse physiological reactions in healthy adults and one mg/day produced no indications of physiological abnormalities in children.

Allergic reactions to iodine compounds are always due to the organic component of the molecule. Incidental toxic reactions as a result of an increased iodine intake after the introduction of a salt iodization program have been reported. These cases are rare and mostly confined to individuals with an underlying thyroid disease (*"hot nodules"* of goitrous thyroid tissue, which had been present for years) (Lowenstein 1983). A transient, slightly higher prevalence of hyperthyroidism may occur after the introduction of an iodization (i.e., salt) program. This effect is temporal and will disappear within a short period. In some studies, the incidence of thyrotoxicosis has doubled over several years following introduction of iodine into iodine-deficent populations, but the incidence then characteristically decreases to a level below that existing before correction of iodine deficiency (ICCIDD 1995).

Table 3-7. Safety of the micronutrients.

Micro-nutrient	RDI (recom'd dietary intake)	Safety index (MTD/RDI)	MTD (min toxic dose)
Iodine	0.15 mg	13	2 mg
Iron	18 mg	5.5	100 mg
Vitamin A	5,000 IU	2–2.4	10,000–12,000 IU

Source: Adapted from Bailey (1991); Clydesdale (1991); Hathcock (1990); NAS (1989).

IRON

An individual's iron status regulates iron absorption to some extent (Gavin et al. 1994). As the iron store increases, the bioavailability and, thus, the absorption of the dietary iron, decreases. Furthermore, the losses of iron from the body will increase because with increased iron stores, desquamated cells will have a higher iron content (Hallberg 1993). For this reason, there are no reports of iron toxicity in healthy subjects from iron-containing foods. One exception has been reported resulting from long-term ingestion of homemade brews in iron vessels (Gordeuk 1986). Changing beer-producing and drinking habits of the urban population has significantly reduced the prevalence and severity of the dietary iron overload in the urban population. Perhaps only in the rural population of sub-Saharan Africa does the issue remain a public health concern.

VITAMIN A

Vitamin A fortification of foods in dosages not exceeding the RDI does not cause toxic effects. Usually, small excesses of vitamin A for short periods do not exert any harmful effects. Sustained daily intakes, from both foods and supplements, that exceed 50,000 IU in adults and 20,000 IU in infants and young children may cause toxic effects.

Carotenoids are not known to be toxic. A high intake may, however, cause a discoloration of the skin, which will gradually disappear when the high intake is discontinued (NAS 1989). Nevertheless, fortification levels for food fortification programs aimed at the general population have to be established with extreme caution.

SINGLE FORTIFICATION

In the context of this report, single food fortification refers to fortification of food vehicles with either iodine, iron, or vitamin A (whether or not other types of (micro)nutrients are also added to the same food vehicle is not considered here).

IODINE

A variety of vehicles for iodine supplementation in the diet such as salt, bread, tea, sugar, sweets, milk, and water have been tried over the past 60 years. The iodization of salt has become the most commonly used method of iodine prophylaxis in most countries in the world. This is because of its advantages from the points of view of uniformity of consumption, universal coverage, acceptability, and simple, low-cost

technology. In Table 3-8, vehicles suitable for single fortification with iodine are listed and, in Chapter 7 in the section "Project Experiences in Single Fortification with Iodine," more information is provided.

IRON

Wheat-flour and cereal-based foods: In developed countries wheat-flour and cereal-based foods have had significant success as vehicles for iron. Fortification of milled cereals (such as wheat and maize) has also been adopted in several countries in Latin America and the Caribbean as a result of government regulations.

Infant weaning foods: As breastmilk gradually becomes insufficient to meet the iron requirements of a growing child after 6 months, infant foods and formulas can be used for supplementation. They generally consist of a cereal (wheat, rice, maize, sorghum), a high-quality protein compound (soybean, nonfat dry milk, whey), and a fat component. The food should be fortified with vitamins and minerals. Small quantities of sugar can be added as flavouring. The ingredients may be milled and processed, i.e., heat treated, rolled, par-boiled, or extruded. In preparations of infant foods to be used in any given area, local ingredients should be used as much as possible. If planned and prepared appropriately, the result will be a nutritionally improved product compared to any of the single ingredients used in the formulation. The final product can be sold to consumers as a drink or in a dry form for later cooking like rice.

Salt: Encouraging results of iron fortification of salt have been reported from India and Thailand, but more efforts are focused now on developing a formulation that will permit the addition of both iodine and iron (see also Chapter 8).

Sugar: Sugar is an attractive vehicle for iron fortification in sugar-producing areas like the Caribbean and Central America.

Rice: Because rice is a staple food for more than half the world's population, and is the main component of the diet in many countries where the prevalence of IDA is high, iron fortification of rice is a logical choice. Since 1949, efforts in iron fortification have been made. There is, however, still no large-scale program in operation. Research is now focusing on multiple fortification of rice with iron and vitamin A (see Chapter 8).

Curry powder and fish sauce: Dark-coloured foods with a strong taste like curry powder and fish sauce are particularly suitable for iron fortification because the iron sources generally have a slightly dark colour and often have a metallic taste.

Other foods: Foods that have been fortified with iron include bakery products, beverages, biscuits, low-fat milk, chocolate milk, maize-flour, margarine, and water. In Table 3-9, vehicles suitable for single fortification with iron are listed, and more information is given in Chapter 7 in the section on "Single Fortification with Iron."

VITAMIN A

Sugar: Fortification of sugar with vitamin A has been successfully implemented in several countries in Central America in the 1970s.

Oils, fats, and margarine: In several countries, margarine, hydrogenated oil, and shortening are being fortified with vitamin A palmitate .

Monosodium glutamate (MSG): Efforts to fortify MSG (a widely consumed condiment in Indonesia) with vitamin A are in progress.

Tea: Fortification of tea with vitamin A has been established in India and Pakistan and is being considered in Tanzania.

Other foods: Food vehicles that can be fortified with vitamin A include milk/milkpowder, whole wheat, rice, salt, soybean

Table 3-8. Food vehicles with potential for single fortification with iodine.

Vehicle	*Fortificant*	*Stability*	*Bioavailability*	*Status*
Bread	Potassium iodate (KIO_3)	n/a	good	+
(Brick) Tea	Iodine	n/a	good	n/a
Milk	Iodophor++	good	n/a	+
Salt (Purified)	Potassium iodide (KI)	poor	good	+
Salt (Impure)	Potassium iodate (KIO_3)	fair	good	+
Sugar	Iodine	n/a	good	lab
Sweets	Iodine	n/a	good	lab
Water	I_2 or KI or KIO_3	n/a	good	+

Note: + = ongoing; lab = laboratory stage; n/a = not stated, ++ = this is unintended addition of iodine through sterilization of cow udders.

oil, peanut butter, and infant formulas. In Table 3-10, vehicles suitable for single fortification with vitamin A are mentioned. When available, more information is given in Chapter 7 (Single Fortification with Vitamin A).

MULTIPLE FORTIFICATION

In the context of this report, multiple fortification refers to fortification of food vehicles with two or more of the three major micronutrients (iodine, iron, and vitamin A). Fortification with other micronutrients, such as B vitamins, vitamin C, zinc, folic acid, etc., is not considered here.

Multiple food fortification may be a way to address two or all three major micronutrient deficiencies in a more cost-effective manner. Multiple fortification of cereal and weaning foods/formulas has already been done successfully. Micronutrient multimixes for cereals (primarily wheat) in addition to iron and/or vitamin A often include thiamine, riboflavin, and niacin. Examples of commercially available cereal fortification multimixes produced by different manufacturers are shown in Appendix 4. Opportunities for multiple fortification of foods are still limited. Some possible vehicles for such purposes are shown in Table 3-11.

Table 3-9. Food vehicles with potential for single fortification with iron.

Vehicle	*Fortificant*	*Stability*	*Bioavailability*	*Status*
Wheat flour	Elemental iron Ferrous sulphate	good fair	good good	+ +
Infant cereals Infant formulas CSM/CSB/WS -other	Elemental iron Ferrous fumarate Ferrous sulphate	good good fair	fair good good	+ + +
Maize meal	Elemental iron	good	good	+
Potato starch	Ferric chloride Ferric citrate	fair fair	fair poor	lab discontinued
Processed cereals	Ferrous fumarate Ferric orthophosphate	n/a good	good poor	n/a discontinued
Rice flour	Bovine haemoglobin concentrate	fair	good	exp
Bread	Ferrous sulphate	fair	good	exp
Salt	Premix: ferrous sulphate/sodium- acid-pyrophosphate/sodium-acid-sulphate Ferric orthophosphate	n/a n/a	good good	+ lab
Sugar	Ferrous sulphate Ferric orthophosphate Ferrous-sodium-EDTA	good n/a good	good n/a fair	exp n/a exp
Milk powder	Ferrous sulphate	fair	fair	exp
Cheese	Ferrous sulphate + ascorbic acid	good	good	lab
Coffee	Ferrous fumarate	good	fair	exp
Curry powder	Ferric-sodium-EDTA	good	good	exp
Eggs	Ferric citrate	fair	poor	lab
Fish sauce	Ferric-sodium-EDTA	good	good	exp
'Kool-aid'	Ferrous sulphate	fair	good	exp

Note: + = ongoing; exp.= experimental/field trials; lab = laboratory stage; n/a = not available.

Table 3-10. Food vehicles with potential for single fortification with vitamin A.

Vehicle	*Fortificant*	*Stability*	*Biovailability*	*Status*
Sugar	Premix: vit A palmitate 250-SD or -/acetate 325-L = peanut oil + stabilizer	good	good	+
Fats and oils	ß-carotene-vit A ester	good	good	+
Cereal grain flour	Vit A palmitate or dry retinyl palmitate	fair	good	lab
Infant foods	Vit A palmitate	n/a	n/a	+
Milk powder	Encapsulated retinyl palmitate	good	n/a	+
Rice	Premix: vit A palmitate 250-SD + antioxidants + preservatives + lipids	good	n/a	exp
Tea dust Tea leaves	Vit A palmitate 250 SD Vit A palmitate 250-SD + vit A acetate + sucrose + antioxidants + preservatives	good	n/a	exp
Whole wheat	Premix: vit A attached to wheat grains	n/a	n/a	lab
MSG (Monosodium glutamate)	Vit A palmitate 250-CWS + carbohydrate + antitoxidants + white pigment coating	fair	good	exp
Peanut butter	Vitamin A palmitate	good	n/a	exp
Salt	Vit A palmitate	good	n/a	exp
Yoghurt	Vit A palmitate	good	n/a	lab

Note: + = ongoing; exp = experimental/field trials; lab = laboratory stage; n/a = not stated.

Some possible vehicles for multiple fortification with micronutrients:

Fortificants	*Vehicle*
Iodine+vitamin A	Rice, MSG, sugar, wheat flour, and infant foods
Iodine+iron	Salt, fish sauce
Iodine+iron+vitamin A	Processed foods and infant foods

These technologies are yet to be fully developed as stable formulations in a way that the relative absorption of the micronutrients added are not adversely affected. There have been some scattered efforts to fortify salt with both iron and iodine. The Micronutrient Initiative is currently funding a research project with the University of Toronto, Canada, to investigate this issue thoroughly by means of a collaborative effort among various investigators. The aim of this research activity is to provide fortified salt with both iodine and iron so that these two micronutrients are supplied in the diet in a stable and bioavailable manner. Field trials are now planned to test the developed formulation for double fortified salt in developing and developed countries.

In recent years, there has been an increased interest for ready-made weaning foods to supplement breastmilk after 6 months of breastfeeding. In most cases, home prepared weaning foods are the best solution, but there are several constraints that have hampered preparation and marketing of local weaning foods. Some of these are poverty, lack of current knowledge and existence of taboos, non or irregular supply of raw materials, time constraints for preparation, shortage of fuel/clean water for cooking, poor hygiene practices, short storage time, and low social prestige value for homemade products. Availability of ready-made weaning foods can overcome some of these constraints.

Many efforts have been made to develop commercial, low-cost, multiple fortified weaning foods. Since the 1950s, large-scale industrially produced weaning foods have been subsidized by international organizations like FAO, UNICEF, and the World Food Programme (WFP), in an attempt to popularize the products in developing countries. Nevertheless, experience has shown that large-scale local production of weaning foods hardly met with any commercial success. The use of these products remained restricted to the urban population with higher purchasing power. Only Incaparina (Guatamala) and Pronutro (South Africa) had some success. Other weaning foods produced on a large scale have never gained an important market position. Suparamine (Algeria), Faffa (Ethiopia), Balahar, Bal Amul, Multi Purpose Food (India), Soy-Ogi (Nigeria), and

Table 3-11. Food vehicles with potential for multiple fortification.

Vehicle	*Fortificant*	*Stability*	*Bioavailability*	*Status*
Cereal based food	Fe, I_2 and vit A	good	n/a	+
Fish sauce	Fe as NaFeEDTA I_2 as potassium iodate (KIO_3)	n/a	n/a	exp
Infant formula	Fe, vit A (and I_2)	n/a	n/a	+
Maize meal	Fe as elemental iron Vit A as retinyl palmitate	good fair	fair n/a	+ +
Milk powder	Fe as ferrous sulphate ($FeSO_4$) and vit A	n/a	n/a	+
MSG (Monosodium glutamate)	Fe as ferric orthophosphate Vit A as vit A palmitate or Fe as zinc stearate coated ferrous sulphate Vit A as vit A palmitate	good fair good fair	good good good good	lab exp lab exp
Rice	Fe as ferric orthophosphate Vit A as retinyl palmitate	good fair	poor n/a	lab exp
Salt	Fe as ferric fumarate I_2 as potassium iodide (KI)	fair n/a	good n/a	exp exp
Weaning rusk	Fe as ferric ammonium citrate Vit A as retinyl acetate	poor n/a	good n/a	lab exp
Wheat flour	Fe as elemental iron Vit A as retinyl palmitate	good fair	fair n/a	+ +

Note: + = ongoing; exp. = experimental/field trial; lab = laboratory stage; n/a = not available.

Lishi (Tanzania) are examples of multiple fortified weaning foods mostly distributed free (Caritas Neerlandica 1983) for use in supplementary feeding programs by international organizations or governments. In Table 3-11, vehicles suitable for multiple food fortification are mentioned. Chapter 8 (Opportunities for Multiple Fortification) provides more information.

Small-scale production of weaning foods is often linked to another development program, and such products are predominantly used in rehabilitation centres. There are, however, uses and markets for these products outside recovery clinics for malnourished children and charity programs. Many poor households with weaning-age children can benefit from such products if they are appropriately made, have high nutritional quality, and can be afforded by these families. Production costs are relatively low when local raw materials, simple technology, and local management and labour are used. In 1986, the Royal Tropical Institute (KIT) presented the blueprint for a "new approach to low-cost weaning food production," based on the experience of the "Farine Bébé" project at the CHNO in Benin (Altes and Merx 1985; KIT 1987), which proved to work in practice.

In this approach, emphasis is given to the self-sustaining character and the gradual expansion possibilities of planned activities. Projects in various countries in Africa, Asia, and Latin America carried out under the auspices of the Netherlands government (Benin, Burundi, Mozambique), EC (Sierra Leone), Caritas Neerlandica (Dominican Republic, Ghana, Jamaica), NOVIB (Ghana), and WFP (Bangladesh, Ethiopia, Kenya, Malawi, Nepal), have shown that a low-investment, labour-intensive project for manufacturing weaning foods on a semi-industrial scale from indigenous raw materials can be successful (Dijkhuizen 1992). Although addition of micronutrients in most cases was not considered, there are no technological constraints for multiple fortification of these weaning foods.

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4. FOOD FORTIFICATION TECHNIQUES

Once the micronutrient(s) to be added and the suitable food vehicle are selected, fortification is done basically in a mixing process. The goal is to deliver adequate micronutrients without adversely affecting the characteristics of the vehicle. This seems to be quite straightforward, yet finding the right processing point for such additions in the manufacturing chain of processed foods needs careful consideration.

FORTIFICATION PROCEDURES

Depending on the food processing technologies, different addition methods have been developed:

- *Dry mixing* for cereal flours and products, powder milk, powder beverages;
- *Dissolution in water* for liquid milk, drinks, fruit juices, and in the water to be used for making bread, pastas, and cookies;
- *Spraying* as in iodization of salt and corn flakes where the vitamins do not support the cooking or extrusion step;
- *Dissolution in oil* for the liposoluble vitamins for enrichment of oily products like margarine;
- *Adhesion* for sugar fortification where the vitamin A in powder form is adhered to the crystals surface by a vegetable oil;
- *Coating* as in rice where the vitamins sprayed over the grain must be coated to avoid the losses when washing the grains before cooking; and
- Extrusion as in rice where vitamins are mixed with powdered cereal using binding agents and extruded into whole cereal grains.

The simplest way to add one or more micronutrients to a food vehicle is to use a mixing procedure. Even when more sophisticated techniques (e.g., encapsulation or reconstitution of rice grains fortified with vitamin A) are employed in specific situations and for specific purposes, mixing will still be required for uniform dispersion in the food vehicle.

Depending on the nature of the mixed components, various types of mixes can be distinguished: solid-solid, solid-liquid, and liquid-liquid. Most dry foods are fortified using a dry premix. (Information on procedures/distributors of premixes and fortificants can be obtained from the Micronutrient Initiative.)

SOLID-SOLID MIXING (DRY MIXING)

The most common method of fortifying dry foods with small quantities of micronutrients is dry blending, either in batches or continuously or with a combination of both. Mixing effectiveness depends on the ingredient properties such as size, shape, density, hygroscopic and electrostatic properties of the particles, as well as proportions of the components being mixed. For uniform mixing and maintenance of mix, homogeneity during processing, packaging, and storage and distribution, the ingredient properties of all additives should be as close as possible. The larger the differences, the easier segregation will occur.

The choice of mixing equipment depends largely on the requirements of the mixing operation. Mixer attributes, which can greatly affect the mixing effectiveness, include mechanical energy input, particle attrition, batchsize or size of continuous flow, and mixing time. Mixers are widely used in the food industry and are available in a variety of designs and configurations to match the different requirements. The main types of mixers for dry mixing follow.

Batch mixers: In batch systems the micronutrient premix is prepared separately and a specific quantity is added to each batch. The most common batch mixers are:

- ***Drum mixers:*** The simplest type of mixers, which consist of a horizontal rotating drum with or without ribbons.
- ***Screw mixers:*** A popular mixer is the "Nauta" mixer, a vertical cone mixer, which consists of an inverted cone fitted with circulating screw agitators (Fig. 4-1a).
- ***Ribbon blender:*** The horizontal ribbon blender consists of a rotating shaft fitted with two helical ribbons, which rotate in opposite directions inside a semicircular trough (Fig. 4-1b)
- ***Continuous mixers:*** For continuous systems, the fortificant is added through a volumetric or gravimetric solids feeder at a rate compatible with the flow rate of the food vehicle to ensure the correct dosage in the product. Commonly used continuous mixers are screw conveyors (often with cut and folded flights and/or paddles).

Fig. 4-1a. The "Nauta" mixer.

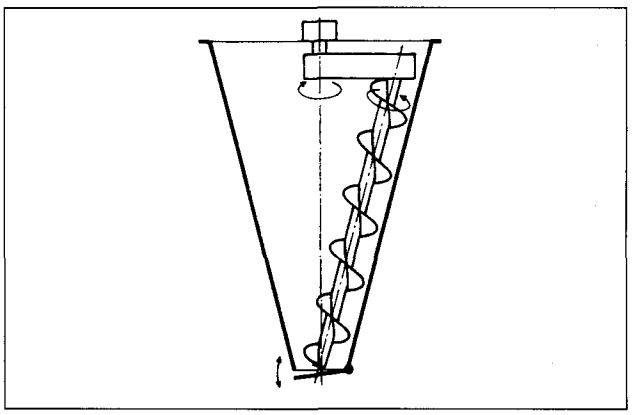


Fig. 4-1b. The Ribbon blender.

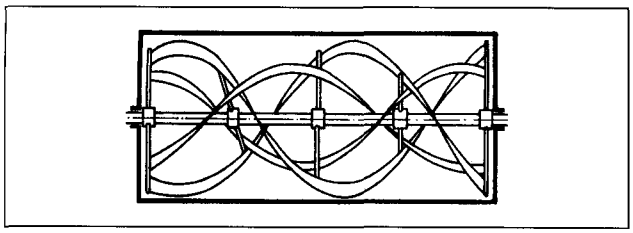
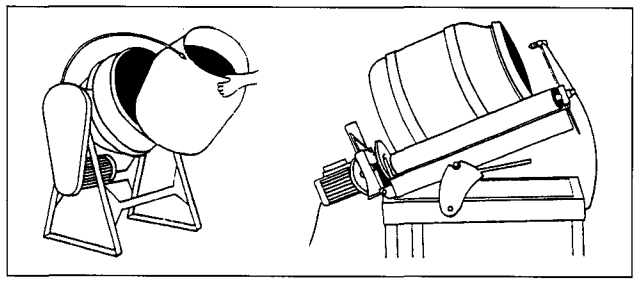


Fig. 4-2. Two types of rotary drum salt iodization units.



SOLID-LIQUID MIXING

If the fortificant or premix is in liquid form then the fortificant should be fed to the food vehicle by spraying, where the fortificant is added in a solution form as an atomized spray. Spray nozzles are positioned over a belt conveyor or a screw conveyor or inside a rotating drum. Both the "Nauta" mixer and ribbon blender are used for mixing liquids into solids by mounting spray nozzles.

For iodization of salt crystals, drip-feeding, where the fortificant is added in solution form to the dry salt, is still commonly used, but spray mixing is increasingly preferred (Mannar and Dunn 1995). Figure 4-1c is a schematic elevation of a continuous spray mixing plant for salt iodization.

For small-scale production of fortified foods, simple low-cost mixing equipment can be used. One can think of handmixing and the use of a rotary drum unit that works like a cement mixer (Fig. 4-2).

LIQUID-LIQUID MIXING

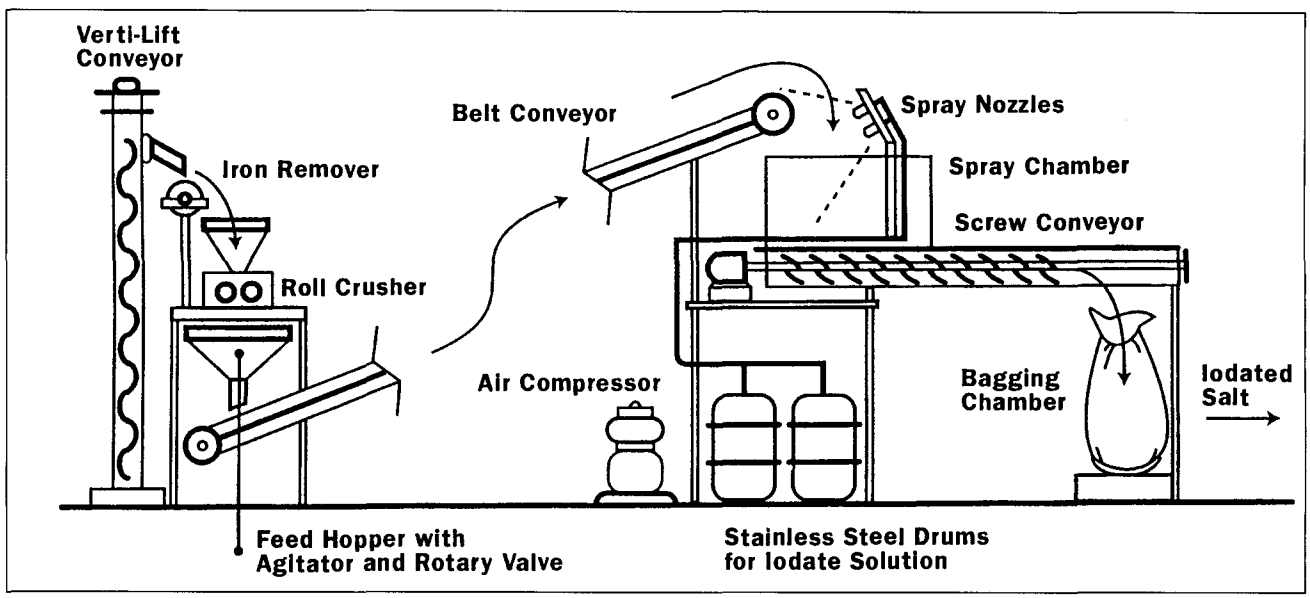
For liquid or semimoist foods, the micronutrient is dissolved or dispersed in a liquid vehicle (water or oil) and subsequently blended or homogenized into the product. The mixing is done in vertical tanks filled with turbine or propeller agitators. The effectiveness of the mixing depends upon a number of factors such as viscosity, flowing characteristics, and mixability of the components, as well as proportions of the components being mixed. For micronutrients such as vitamin A, vitamin C, and B vitamins, which are subject to oxidative degradation, antioxidants are added to the premix. Furthermore, exposure to oxygen and divalent ions is minimized.

ENCAPSULATION

Encapsulation is a process of coating dry, free-flowing powder particles. Depending on the size of these particles, the technology is referred to as microencapsulation (coating liquids and super-fine powder particles of 500 microns and under), or macroencapsulation (coating of larger particles of 5,000 microns and above). Coating powder particles between this range (500 and 5,000 microns) is simply referred to as encapsulation (with no micro or macro prefix added). The primary objective of encapsulation is to extend shelf life and quality of the product by separating the fortificants from the vehicle's components and environment until release is desired. Despite a slow development of the encapsulation technique over the past few years, its application in the food processing industry is now growing rapidly.

Encapsulation is used to mask undesirable flavours and to isolate reactive components to prevent the degradation of micronutrients. In multinutrient fortification, the use of

Fig. 4-1c. Spray mixing plant for salt iodization (with precrushing).



encapsulation will help to provide barrier protection to separate the micronutrients from one another to avoid adverse nutrient–nutrient reactions. For encapsulating vitamins, modified food starch or vegetable fats may be used as a coating agent. Encapsulated vitamins offer reduced after-taste and off-flavours; are protected from hygroscopic, thermal, or oxidative degradation; and have enhanced shelf life, better flowability, and less dusting (Duxbury and Swientek 1992). In developing a stable formulation to fortify salt with both iron and iodine, the University of Toronto has, under a Micronutrient Initiative-funded study, used a new technique of dextrin microencapsulation to create a barrier between ferrous fumarate and potassium iodate. Acceptability and bioavailability of the micronutrients using this formulation are proposed to be studied in a series of trials.

CEREAL GRAIN RECONSTITUTION

Cereal grain reconstitution involves the reconstitution of broken rice grains into whole grains. In the manufacturing process, rice flour made from broken rice grains is mixed with this premix containing all-trans retinyl palmitate, a small amount of maize oil, and lard of food grade. A new formulation replaces lard with other types of oils like coconut or peanut oils. Alpha-tocopherol and ascorbic acid are added at 1 mg/g premix. The fortified grains are then reshaped as rice grains and mixed with regular rice at a ratio of 1:100 to 1:200, depending on the patterns of rice consumption of the vitamin A-deficient population to be served. The proprietary binding agent protects the fortificant during rinsing and cooking.

POINT OF FORTIFICATION

The method of micronutrient addition is frequently dependent on the manufacturer's processing system, packaging and food preservation techniques, the commodity to be fortified, the fortificant to be added, and the processor's preferences. For better stability profiles, the fortificant should be added *after* processing as in the case of flaked cereals, although this can cause separation. In some cases, therefore, the fortificant must be added *before* heat processing steps as in canned foods. To identify suitable and convenient point(s) where fortification can be integrated with the prevailing system at minimum additional cost, the whole manufacturing process from production/importation points to the consumer should be carefully studied.

One of the most important factors affecting the point-of-addition of a micronutrient or premix is the stability of the micronutrients. Operations such as cleaning/rinsing, cooking, aeration, heating, extrusion, or drying, etc., may significantly affect the biological functions and stability of the added nutrients. Iodine, for example, is subject to vaporisation when exposed to excess heat during processing. Iron compounds are subject to oxidation and colour changes. Vitamin A is subject to oxidation, hydrolysis, and biochemical reactions that could reduce its potency. The importance of any of these factors is dependent on time, temperature, oxygen, and composition of the food. Consequently, it is advisable that certain micronutrients be added to the foods after unit operations involving heating, aeration, and washing (Lund 1991).

As a general guideline, addition is preferred at that point in the process that will:

- Provide sufficient agitation to ensure that the nutrients are uniformly distributed,
- Present the food at some fixed, known volume or weight,
- Provide for ease of addition, and
- Eliminate as many adverse processing conditions as possible (Parman and Salinard 1963).

For products imported at a single entry point by a single large importer, the point-of-addition could be at the point-of-entry where the product is invariably repacked. This, however, depends on cost and available resources. For products imported from one production source by multiple importers, it is best to specify that the product be fortified at the production source at the prescribed level. Sometimes, a combination of the foregoing strategies will have to be adopted.

There are pros and cons for locating the fortification plants either at the point-of-manufacture or close to the consuming areas. If the plant is located at the production point, there is minimum additional handling involved, but losses in transit and storage are possible. If the fortification plants are located at the consumption points, losses would be minimized, but multiple handling and storage might make it uneconomical.

The question also arises as to which agency would own and operate these plants at the consumption centres and bear the additional handling charges. The consensus is in favour of locating the plant as close to the point of production as possible and/or just before packing to maximize retention of the fortificant (Mannar and Dunn 1995). Table 4-1 summarizes the preferable point-of-addition for a number of foods.

PACKAGING

To minimize micronutrient losses during storage, the fortified food should be properly packaged. The retention rate of the micronutrient in foods depends on the fortificant used, the type of packaging, the exposure of the package to prevailing climatic conditions, and the time elapsed between the moment of fortification and actual consumption. Because of a lack of availability of packaging material in many developing countries, packaging assumes great importance. In some cases, an available source of appropriate packaging material is found before the product is designed (Fellows and Axtell 1993).

Fortified food-production centres are often far from the consumption areas, therefore, adequate precautions should be taken to ensure that these foods ultimately reach the consumer with the recommended level of fortificant. For this reason, shelf-

Table 4-1. Point-of-addition of a dry premix of micronutrients to food vehicles.

Vehicle	*Form of micronutrient*	*Point-of-addition*
Baked items	Coating, spraying, or dry premix	In water-flour mix
Beverages	Solution or dry premix	Before pasteurization
Bread	Tablet or dry premix	Water-flour mix
Breakfast cereals (dry)	Coating or spraying	After toasting
Cereals (cooked)	Dry premix	Last mixing stage
Cheese (processed)	Solution or dry premix	During blending
Cheese (primary)	Solution or dry premix	Before curdling
Maize grits	Dry premix	End of miling
Maize meal	Dry premix	During milling
Wheat flour	Dry premix	During milling
Fruit juice	Solution	Before pasteurization
Infant food (dry)	Dry premix	During mixing
Infant food (liquid)	Dry premix	Prior to homogenization
Margarine	Emulsion	Before churning
Milk	Emulsion	Prior to homogenization
Milk powder	Dry premix	Before instantizing
Pasta products	Dry premix	In water-dough mix
Peanut butter	Dry premix	With salt addition
Potato chips	Dry premix	Coat after toasting
Rice	Coating, spraying or dry premix	After milling
Salt	Spray mixing or dry premix	After milling
Snack food	Coating, spraying or dry premix	After heat processing
Soups (dry)	Dry premix	During mixing
Soups (processed)	Dry premix	Before pasteurization
Soya flour	Dry premix	During mixing
Sugar	Dry premix	During blending (dry)
Tea leaves	Dry premix	During blending
Vegetable oil	Direct fortification	Followed by blending

Source: Adapted from Bauernfeind and Brooke (1973).

life testing is highly recommended. Hygroscopic products like flour and salt easily attract moisture and become wet when improperly packaged and transported over long distances under humid conditions. This causes biochemical and microbiological deterioration. Efforts should be made to improve the distribution network to reduce the time between fortification and consumption of foods.

Packaged foods should be marked to identify the contents for monitoring purposes. Ideally, the package should also be marked with the production date of the content so that the time elapsed between fortification and consumption can be calculated. All packages should carry expiration dates to ensure that the product still has the adequate amount of the fortificant. The stipulations for handling, transportation, storage, and sales of iodized, packaged salt as described in Table 4-2 are also applicable for other fortified foods (Mannar and Dunn 1995).

PACKAGING MATERIALS AND CONTAINERS

There are two types of packaging materials: rigid containers and flexible packaging.

Rigid containers include glass and plastic bottles, jars, cans, pottery, wood, boxes, drums, tins, plastic pots, and tubes. They all, to a varying degree, give physical protection to the food inside that is not provided by flexible packaging. On the one hand, some types of rigid packaging have the advantage of providing a perfect hermetic seal. On the other hand, although most rigid containers are strong, they are more expensive than flexible packaging. Glass jars are not suitable as packaging materials for foods that are adversely affected by light unless the jars are stored in a dark place or if the fortified food stored in a glass jar stays stable on exposure to light.

Flexible packaging that can be used to make wrappings, sacks, and bags includes plastic films, papers, foil, some types of vegetable fibres, and cloths.

Packaging options for groups of foods are described by Fellows and Axtell (1993):

Hygroscopic foods: When packed for the humid tropics, hygroscopic foods such as wheat flour, maize flour, and salt require a moisture barrier. These foods should be packed in

Table 4-2. Stipulations for handling, transportation, storage, and sales for packaged fortified foods.

- Do not expose food to water, excessive humidity, and/or direct sunlight at any stage of storage, transportation, or sale.
- Transport, store, and keep the food for sale in the original packing only.
- Store bagged food only in covered rooms with adequate ventilation.
- Stack bagged food on wooden pallets (raised at least 10 cm above floor level).
- Avoid the bagged food making direct contact with the walls of storage rooms or warehouses.
- Do not use hooks or pointed or sharp instruments when handling the bags.
- Keep a stock register with batch numbers and the date of receipt and despatch.
- Despatch, distribute, and sell the food strictly according to the principle of first in first out.
- Agents, distributors, and retailers should cooperate with government-designated inspectors in the inspection of fortified food stocks and the drawing of samples.
- Fortified foods may be sold by retailers only if the period between the date stamped on the bag and the date of sale is less than 6 months. Samples of all date-expired foods shall be sent to a designated authority for confirmation regarding adequate micronutrient content. If not adequate, the food shall be returned to the appropriate agent or distributor for free replacement.
- Agents and distributors of fortified foods shall return all foods that are date-expired or do not conform to the minimum standard of fortification to a designated authority for free replacement.
- Retailers shall advise consumers to store fortified foods in such a manner as to protect them from direct exposure to moisture, heat, and sunlight.
- Retailers shall replace, free-of-charge, any fortified food purchased by a consumer and subsequently certified to be not conforming to the minimum standard of fortification. Such food shall be kept separately and returned to the distributor or agent for free replacement.
- Bags of fortified food may be stored temporarily after opening only for purposes of retail sale. Such bags shall be kept covered or closed at all times.
- Retailers shall prominently display the government approval, sign boards, and posters relating to fortified foods.

Source: Adapted from Mannar and Dunn (1995).

airtight bags or containers. In many countries, this implies a major switch from conventional packaging materials, like straw or jute, to the more expensive plastic lined bags and other containers. The packaging units in the case of bulk packaging should not exceed 50 kg (in accordance with International Labour Organization (ILO) regulations) to avoid the use of hooks for lifting the bags. Bags once used for packaging other articles such as fertilizers, cement, chemicals, etc., should not be used for packaging fortified foods.

Edible oils and fats: Cooking oils are susceptible to rancidity, therefore, lightproof and airtight packaging is required. Metal cans, glass, and possibly plastic bottles are the most suitable containers.

Dairy products: Microbial contamination is the major problem in using dairy products as a vehicle for fortification. Packaging should be sterilized to prevent contamination after processing. During distribution and storage the products should be kept cool and away from direct sunlight. Polyethylene bags are adequate if the product is carried home and consumed right away. For long-term storage of cheese, polyethylene should not be used because of migration of chemicals from the plastic into the fatty food. For distribution purposes, reusable glass bottles with foil lids are used as a relatively low-cost package for milk.

Bread: Because of its short shelf life, packaging bread is mainly used to keep these products clean and is usually not used as a barrier to moisture or air. Clean paper is an adequate packaging material. If polyethylene film is used, condensing on the inside of the bag should be prevented by allowing the baked goods to cool down after baking and before packaging.

Biscuits: When packed for the humid tropics, dry biscuits require a moisture barrier and packaging to resist mechanical damage.

For biscuits with a high fat content a lightproof/airtight packaging to avoid rancidity is also required. Cardboard cartons coated with polypropyiene or cellulose film is applicable. The use of polyethylene should be discouraged because of the migration of chemicals from the plastic into the fats contained in the biscuits.

In dry areas, the foregoing constraints are not of importance. In these areas, the packaging is simply used as a way to store the food and to keep it clean.

Beverages: Fruit juices, which are intended for immediate consumption after opening, rely on pasteurization for their preservation. The packaging is used to prevent recontamination by microorganisms. Glass jars, cardboard cartons coated with polypropylene or cellulose film, or coated metal tins are applicable.

Cereals/flour: Like hygroscopic foods, these also require a moisture barrier and should be packed in airtight bags or containers.

Peanut butter: Although peanut butter is yet to become popular in developing countries, it can be a good source of protein and micronutrients. Peanut butter is susceptible to rancidity because of the high oil content. The packaging used must be lightproof and airtight. Metal cans and glass bottles are the most suitable containers.

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5. QUALITY ASSURANCE AND CONTROL

Ensuring the adequacy and quality of fortified food products from production to consumption is a most critical component of any food fortification program. It should be a primary concern of the food industry to validate the consistency of the manufacturing process to release a uniformly fortified product for distribution that has all the intended characteristics and qualities. The availability of trained staff to carry out the procedures adequately is of great importance for a successful outcome.

REQUIREMENT FOR QUALITY ASSURANCE (QA)

The word "quality" has been defined in various ways. According to the standard definition, quality is "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (ISO 1987). Another popular definition is "fitness for use," which is very similar to the standard definition but less neutral. Teboul (1991) introduced a more dynamic aspect when he defined quality as "the ability to satisfy needs at the time of purchase and during use at the best cost, while minimizing losses and surpassing the competition." The two terms, quality assurance and quality control, are often used interchangeably, although based on the WHO (1990) definition, there are differences between the two.

Quality control (QC) is the part of good manufacturing practice (GMP) that is concerned with sampling, specifications, and testing, and with the organization, documentation, and release procedures that ensure that the necessary and relevant tests are actually carried out and that products are not released until their quality has been judged to be satisfactory. Quality control is not confined to laboratory operations but must be involved in all decisions that may concern the quality of the product.

Quality assurance (QA) is a wide-ranging concept that covers all matters that individually or collectively influence the quality of a product. It is the total of the organized arrangements made and applies to equipment, product design, supplies and logistics, management and human resource development, and all elements with the objective of ensuring that products are of a quality required for their intended use at the consumer level.

Quality assurance as it applies to the laboratory should be differentiated from QA as it applies to the program, which would include incorporation of quality in management, the so called total quality management (TQM) methods.

Total quality management is only one of many methods that have been used to instill a certain focus on customers through recognizing that those involved with the processes need to be involved in the decisions about those processes. All this relates to a managerial attempt to build better QA throughout the ranks by workers.

Quality assurance incorporates GMP, which is that part of QA that ensures that food products are consistently produced and controlled to the quality standards appropriate for their intended use. The QA approach involves the control, evaluation, and audit of a food processing system:

- Quality control involves operational techniques and activities that are used to fulfil requirements for quality (line inspection of supplies, materials, raw materials; operating procedures; and finished products).
- Quality evaluation appraises the worth of all raw and processed products (physical, chemical, sensory, and microbiological analysis).
- Quality audit verifies or examines finished products or even processes over time (shelf life, market review, and consumer complaints).

ESTABLISHING A SUCCESSFUL QA PROGRAM

There are six basic fundamentals that must be carefully considered and clearly worked out for the success of any QA program (Gould and Gould 1988):

- ***Organization of the QA department:*** Quality assurance must start with top management supporting the concept of quality. The need for product quality control should be explained to, and demanded from, all personnel.
- ***Personnel selection:*** Personnel in the QA department must be selected on certain qualifications and trained to be able to fulfill the responsibilities necessary for a successful QA program. It may not be feasible to establish a full QA department in smaller businesses because of cost and staffing issues. These issues must be examined and worked out to have a successful program.
- ***Sampling for product evaluation and line control:*** Adequate sampling, assuming that a QA program is already established, is important. The sample taken of a batch from the production line must be representative and must be selected at random. Poor, inadequate sampling is one of the greatest obstacles to achieving successful control of product quality.
- ***Standards and specifications:*** Quality assurance and product control follows the establishment of ingredients and product and process specifications. No other facet of quality assurance is more important than the establishment of specifications and the development of standards of quality for product evaluation. Government agencies involved in food regulation should be committed to quality assurance and control, otherwise the objectives of food fortification may not be met.

- ***Measurement (laboratory, equipment, procedures, and reports):*** The facilities will vary with the size of the operation, the number of products being packed, and the different qualities being packed. Reporting of the results is just as important as the analysis of the samples. Report forms that provide findings and recommendations should be completed daily and kept for future reference. Results should be used to guide management decisions and corrective actions, when needed.
- ***Data collection and interpretation:*** Careful data collection using correct sampling procedures and analysis is critical. The interpretation of the quality control data is one of the more important functions in the successful operation of a QA program. The use of statistical methods can be of great value for the proper interpretation of processes and data.

The basic concept is establishing the routine limits of the system, i.e., through a control chart with calculated upper and lower control limits and then using this chart to demonstrate that the process is "in control." When it is not, there would be specific procedures to follow to determine the cause and to stop production until the problem is resolved. In salt iodization, for example, this would prevent large batches of salt from being released if they did not consistently have the intended iodine in the accepted range.

Steps for Implementation of a Quality Assurance (QA) Program

- Providing specifications for both fortificant and food vehicle (particle size, colour, potency, acceptable ranges of fortificant, fortification level);
- Routinely undertaking hazard analysis of fortificants and fortified foods for chemical, microbiological, and physical contaminants;
- Sampling and testing of fortificants, food vehicle, and fortified food for potency, particle size, colour, net weight, adulteration, packaging, and storage conditions;
- Identifying and regulating the critical control points (CCPs) that might adversely affect fortified foods;
- Establish a recall system to trace or identify the product in case of consumer complaints;
- Auditing and evaluating the QA system on a regular basis to determine whether various elements within a quality management system are effective in achieving stated quality objectives;
- Implementation of corrective actions (detection of quality or safety problems and measures to eliminate the recurrence of these problems); and
- Documenting all aspects of the QA system and making the documentation available to those responsible for the fortified food.

Through quality assurance and control it is ensured that the manufactured food is properly fortified without affecting the organoleptic property of the vehicle, that it is safe to be used, and that it meets all quality standards and government regulations. Fortified foods should be made available at competitive prices compared to nonfortified foods. It should, however, be pointed out that performing a QA program with this degree of sophistication may be difficult in many countries.

DEVELOPMENT AND IMPLEMENTATION OF QA/QC SYSTEMS

The development and implementation of a sound quality assurance and product control system is instrumental to developing an effective, practical, and economical micronutrient fortification of food program. The industry should organize itself in such a way that the technical, administrative, and human factors affecting the quality of its products will be under control. All such control should be oriented toward the reduction, elimination, and prevention of quality deficiencies. The process is in control if:

- The specific product/process parameter complies with the formulated standard at the CCPs at regular intervals, and
- Corrective action is immediately taken if an observation deviates from the specification.

Everyone in the company, from the director to the junior labourer, has a responsibility for assuming a good-quality product. The benefits from meeting these responsibilities are often not fully realized. This results in failure to organize effective quality-control cycles. To be effective, the cycle must be complete. An example of such a quality control cycle is given in Fig. 5-1.

QUALITY MANAGEMENT SYSTEM

A quality management system should be developed and implemented, appropriate to the type of activity and product being offered to achieve maximum effectiveness and to satisfy customer expectations. The quality system typically applies to, and interacts with, all activities pertinent to the quality of a product. It involves all phases from initial identification to final satisfaction of requirements and customer expectations. A schematic representation of the quality loop is shown in Fig. 5-2.

The impact of quality upon the profit-and-loss statement can be highly significant. A company might survive if individual products fail to meet requirements, but if the most senior management fail to appreciate that cost must be identified and measured in relation to quality as part of a company-wide

Fig. 5-1. Quality control cycle.

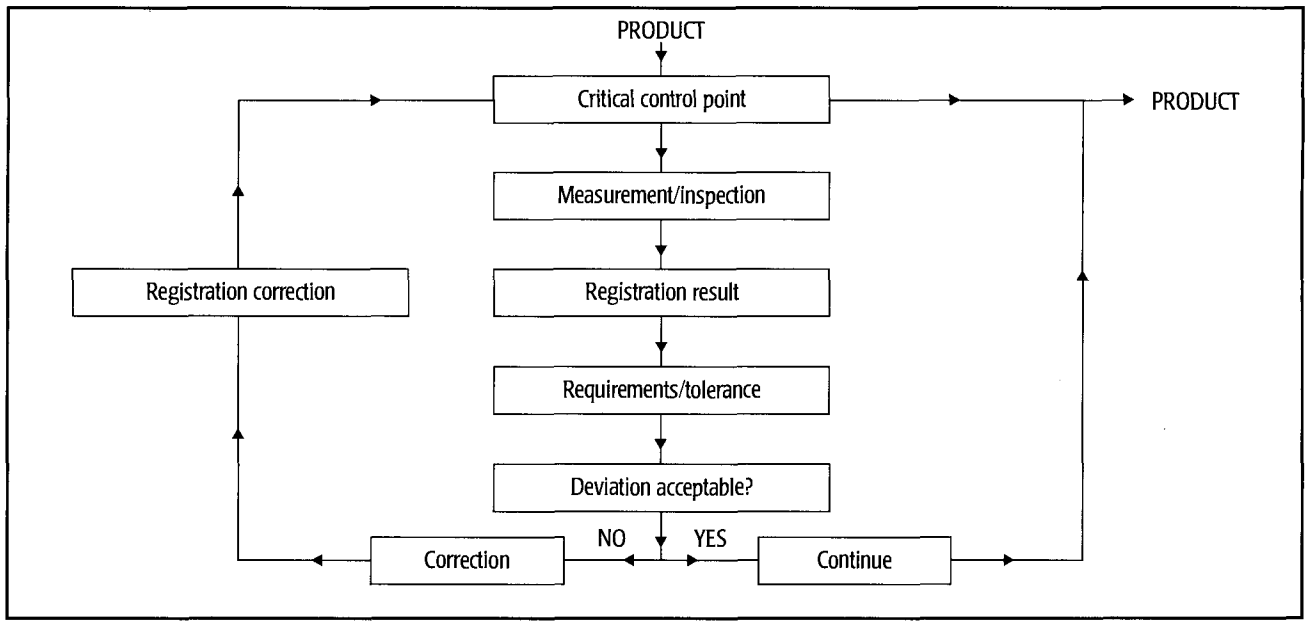
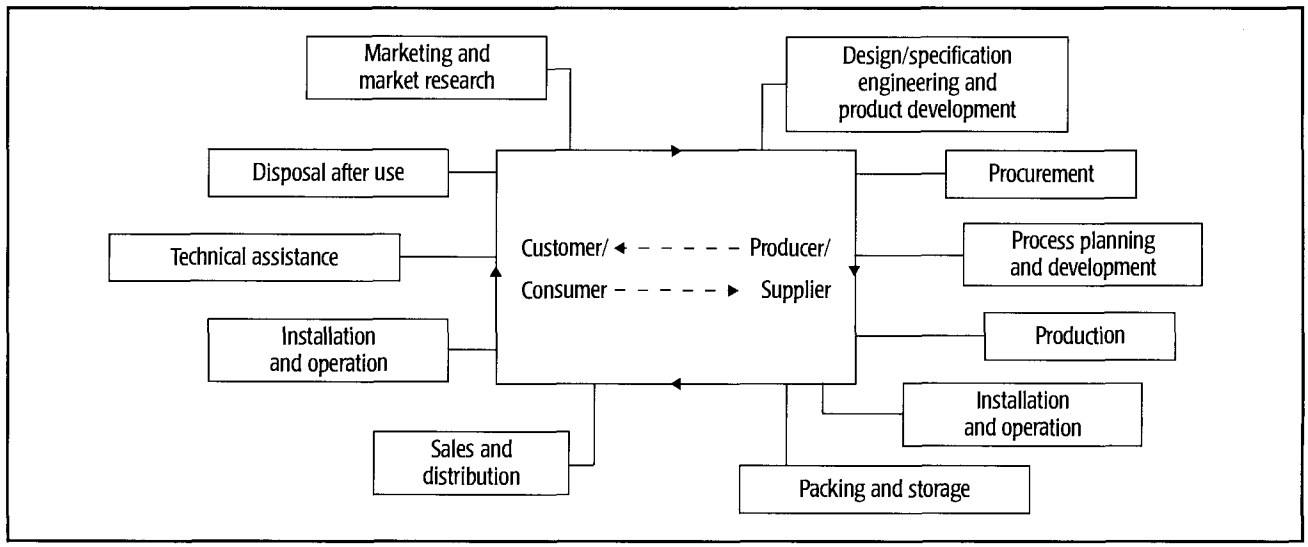


Fig. 5-2. Quality loop.



Source: ISO (1978)

policy, then the company will cease to trade competitively and will eventually cease to trade at all. It is well known that the reported costs of quality are frequently markedly lower than the actual costs of quality. It is not uncommon for the cost of quality to be as high as 25% of sales (Lock 1990).

Both the process and the product of any fortification program need to be monitored. Indicators for monitoring a micronutrient food fortification program should include both the fortification process at the industry end, to ensure constant and appropriate levels of micronutrient in the food, and also the actual consumption of the fortified food by the population. Once the necessary infrastructure and legislation for micronutrient food fortification are in place, fortification levels could be monitored on a regular basis at four levels: the production plant and intermediate points such as wholesale, retail outlets, and households.

At the production plant, the mixing process must be validated. This must include monitoring of micronutrient content during production, and samples must be taken periodically at the end of the processing line to monitor micronutrient levels in the final product.

The responsibility for routine monitoring at the production plant rests with the factory itself (internal monitoring). For example, in the case of iodine, the recommended procedure is to carry out hourly monitoring during production with the *rapid test kit* and confirmed periodically by titration. External monitoring, however, by independent agencies at periodic, regular checks should be promoted.

The steps that specifically require quality assurance are:

1. Purchase quality equipment and supplies;
2. Routinely inspect processing equipment;
3. Validate the mixing process to ensure consistant mixing;
4. Monitor food ready for distribution; and
5. Keep adequate monitoring records.

Source: Adapted from PAMM/MI/ICCIDD/UNICEF (1995).

Legal provisions on monitoring should cover:

Internal, or self-monitoring, by the industry referred to as quality assurance (QA). With internal monitoring, the industry routinely examines its own processes and procedures to identify and correct any problem areas found.

External monitoring by the government pursuant to its inspection and investigation powers. External monitoring provides the government with the information necessary to enforce the law whenever noncompliance with legal requirements is found.

Source: PAMM/MI/ICCIDD/UNICEF (1995, p. 19).

MONITORING BY GOVERNMENT AND BY CONSUMERS

For external QA, the authorized government agency should develop a plan for periodic checking of all producers of fortified products. The frequency of these checks should be adapted to ensure that the food reaching the market meets government standards. External monitoring should increase in frequency when households or retail-level monitoring indicate that some products fail to meet the standard. The steps involved are:

1. Develop standards for fortified foods and the legislations required to ensure that these standards are maintained.
2. Develop a monitoring plan.
3. Establish a list of producers of fortified products to monitor.
4. Monitor producers.
5. Record data.
6. Implement enforcing procedures.

The overall responsibility for quality control inside the country often rests with the Public Health Department, but consumers' organizations can and should also be involved in monitoring micronutrient levels at the off-factory level. The objective of this monitoring activity is to ensure that the product contains the predetermined level of micronutrients added at the consumer level. For example, in India, three nongovernmental organizations (NGOs) in the severely iodine-deficient state of Uttar Pradesh were involved in monitoring salt at the retail and household level. Each month, salt samples were obtained from local retail shops and the results communicated to the community and civic officials. Local politicians were made aware of inadequacies in the iodine content of salt. The issue then went on to be raised in the Provincial and National Parliament (PAMM/MI/ICCIDD/UNICEF 1995, p. 43).[2]

DETERMINATION OF LEVEL OF FORTIFICATION

IODINE

The iodine content in salt can be checked using simple titration techniques or field-testing kits (PAMM/MI/UNICEF 1995). Titration may be used where an accurate determination of the iodine level is required (e.g., at the point of production or import). For routine checking at the field level, a simple test kit made up of a stabilized starch solution can be used. Table 5-1 shows the criteria for assessing the adequacy of a salt iodization program, which has been established by a joint WHO/UNICEF/ICCIDD (1992) consultation.

IRON

Iron content can be determined by a variety of techniques such as a simple colorimetric method or by using an atomic absorption spectrophotometer (AAS). Simple field kits can give a qualitative (not quantitative) indication of the presence or absence of iron. Regular monitoring of iron levels in the product is needed to avoid excess iron addition in case of poor iron distribution during production. Criteria for assessing the adequacy of an iron fortification program can be established similar to those prepared for a salt iodization program (Table 5-1).

VITAMIN A

Assay methods for vitamin A require sophisticated laboratory equipment such as high-pressure liquid chromatography (HPLC). For developing countries semi-quantitive colorimetric test methods are more appropriate because of lower costs (Arroyave et al. 1979). Criteria for assessing the adequacy of a vitamin A fortification program can be established similar to those shown for a salt iodization program (Table 5-1).

[2]A manual entitled "Monitoring Universal Salt Iodization Programmes" has recently been published by PAMM/MI/ICCIDD/UNICEF in response to a strong need for guidance on systematic procedures to establish a permanent, iodized salt-monitoring system within a country. A similar manual is under preparation for a monitoring system suitable for programs dealing with vitamin A-fortified foods. Copies can be obtained from the Micronutrient Initiative or PAMM.

Table 5.1 Criteria for assessing adequacy of a salt iodization program.

	Process indicator	*Criterion of adequacy*
A. Factory or importer level	1. Percentage of food grade salt claimed to be iodized	100%
	2. Percentage of food-grade salt effectively iodized	90% or more
	3. Adequacy of internal monitoring process	90% or more
	4. Adequacy of external monitoring process[a]	10–12 monthly checks per producer/importer per year
B. Consumer and district level	1. Percent of monitoring sites with adequately iodized salt – households (or schools) – district headquarters (including major markets)	Adequacy in 90% of samples
	2. Adequacy of monitoring process[b]	90% or more

[a]Corrective action systematically taken within 3 hours in 90% of cases, following the lot quality assurance methodology.
[b]Monitoring undertaken in 90% of districts in each state, at wholesale, retail, and household level.
Source: WHO/UNICEF/ICCIDD (1992).

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6. LEGISLATION AND REGULATIONS FOR FOOD FORTIFICATION

Effective fortification programs in any country need to be supported by suitable legislation and regulations. To advocate and plan a food fortification program it is essential to ensure the existence of mechanisms through which the entire process can be legally controlled. Two points need to be noted.

First, the mere existence of legislation and regulations is not sufficient to ensure that fortification is taking place. When combined with awareness-raising, among policymakers and the other principal players, however, such legal control can play an important role by helping to accelerate the fortification process and by protecting the consumers from harmful practices that may impinge on their health (e.g., fraud or technological inadequacies in the production of a fortified commodity).

Second, even in the absence of legislation or regulations, the private sector is often capable of taking appropriate action to fortify selected vehicles with micronutrients, and has done so in a number of countries (Nestel 1993). Here again, some level of advocacy and activities to create the need for such micronutrients have played a role in encouraging the action. Nevertheless, to ensure sustainability of these efforts, to prevent unfortified food from entering the country and being consumed in place of the fortified one, and to protect the whole process from the conflicts raised by any antagonistic group, some sort of legal control is bound to be necessary.

Although the laws enacted by the country's legislative organ provide the government with the legal authority to carry out its programs, regulations are rules issued by governmental ministries and departments to carry out the intent of the law and to regulate activities of departments and sections under the guidance of the ministry to ensure uniform application of the law. It is simpler to have a general legislation covering fortification than to have individual pieces of legislation dealing with each activity related to food fortification.

In some cases, in place of legislation, it is quicker and simpler to enforce a regulation (based, e.g., on an existing public health or food law), which does not have to be officially passed by parliament or the head of the state of the country. This is because it is generally easier, both politically and logistically, to change regulations than to introduce and pass legislation to amend an existing law (Nathan 1995). Table 6-1 outlines matters appropriately included in the law versus in the regulations as applied to the example of fortification of salt with iodine.

Once the review of the existing law and regulations is completed, any shortcomings should be communicated to those with the political power to influence legislation and regulations. Experts to assist with drafting amendments to the law and/or regulations should also be involved. If possible, the program manager should seek input from the program perspective to be incorporated into legal provisions governing fortification. If it is necessary to amend the existing law, sponsors must be found to introduce new legislation. Once introduced, the legislation might need lobbying for its passage.

Table 6-1. Matters appropriately included in the law versus in the regulations as applied to the example of salt fortification.

Law	*Regulations*
Requirements for compulsory iodization of all salt intended for human or animal consumption with KIO_3 in compliance with all regulatory requirements	Potassium iodate levels at manufacture, import, wholesale, and retail levels
Requirement that manufacturers, importers, wholesalers, retailers, and transporters must undertake periodic QA activities	QA activities to be undertaken, such as routine equipment and instrument calibration, and sample testing of iodine content
Authority of the government to inspect or investigate any premises where salt is manufactured, imported, received, held, stored, or found, or where it is reasonably believed to be the case	When the government may inspect or investigate, what the government may look at, or how the government may test salt samples
Penalties for noncompliance, including fines, licence suspension or revocation, adverse publicity, or confiscation	The circumstances under which penalty or incentive may be applied, the amounts of fines and periods of suspension, and the procedural steps for imposing penalties
Incentives for compliance, including transport and display priority for iodized salt, exclusive use of logo, and favourable tax treatment	As above

Source: PAMM/MI/ICCIDD/UNICEF (1995, p. 21).

Additionally, monitoring is necessary to watch for any amendments proposed by others that might weaken the law and thus make the program difficult to administer.

If the law is adequate, but the implementing regulations need amending, program managers should alert the appropriate person within the ministry charged with enforcing and administering the existing law. Program managers then should become involved in establishing the standards and requirements that will be contained in the regulations.

Once the law and regulations are in place, program managers should assist in the development of clear guidelines that will help the industry understand and comply with the quality assurance requirements of the law and regulations. The guidelines should be developed in collaboration with industry, NGOs, other ministries, and any other affected groups. Finally, if the proportion of fortificant in the fortified food is not appropriate, the program manager can provide input into the legal process, such as modifying the level of fortificant in production (PAMM/MI/UNICEF 1995).

As the first step in developing such a regulatory mechanism, the following points need to be examined carefully:

- Is a new legislation actually required/desirable or can the existing law adequately regulate food fortification?
- If a change to a law is necessary, should the existing food control law be amended, or will a separate law need to be enacted?
- Is the existing regulatory infrastructure adequate or does it need improvement?
- Should the legislation be limited to fortification with a micronutrient or will a more general food fortification law required? In either case, should the legislation be introduced at the national or provincial level?

The major components that should be covered in the legislation include:

- Mandatory fortification at a level to be determined by the public health authorities of each country.
- Applicability of the measure to all food that is produced, imported, or marketed in the country.
- Designate the government unit, e.g., Ministry of Health, to issue specific enabling regulations for each fortification measure so that it is possible to respond promptly to changing requirements for food fortification without passing new legislation.
- Enforcement and penalties for noncompliance.

To be effective, there should be an efficient system of monitoring to ensure compliance, i.e., the system should be supported by an inspection force that has clearly defined procedures for sampling foods and well-established standards and analytical methods for determining the micronutrient content of fortified food. Legislation and regulations that mandate fortification should create a device for enforcement through a system that fines the defaulters and prevents a continuation of operations if manufacturers do not meet legal requirements embodied in the law.

Regulation of a food fortification program can only be a support measure. It is more important to motivate the food industry to comply through education. Consumer groups whose main objective is to ensure that the public receives high-quality goods and services can play an important role in ensuring that the food sector complies with the regulation. For more information on the subject of legislation and regulation see Nathan (1995).

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7. REVIEW OF RESEARCH AND CURRENT PRACTICES IN MICRONUTRIENT FORTIFICATION

SINGLE FORTIFICATION WITH IODINE

SALT

Countries: A wide range of both developed and developing countries all over the world.

Organizations and groups involved: Ministries of health/industry, salt industry, UNICEF, WHO, ICCIDD, MI, PATH, OMNI, USAID, bilateral agencies, NGOs etc.

Vehicle: Salt fulfils nearly all the characteristics of a suitable food vehicle. Salt is one of the few commodities consumed by all members of the community regardless of social level. It is consumed at roughly the same level throughout the year by all members of a community. Thus a nutrient like iodine when introduced through salt will be administered to each individual at a steady dosage throughout the year.

Fortificants: The two principal fortificants are potassium iodide (KI) and potassium iodate (KIO_3) (see Chapter 3) For quality standards of potassium iodate in salt iodization see Appendix 1.

Fortification level: Current levels of iodization in different countries vary between 20 and 165 ppm potassium iodate (12–100 ppm iodine). In a given country, the level of fortification may be changed over time, in response to changes in average daily consumption of salt and iodine losses during distribution and storage. A sample calculation for fixing the level of iodization in salt is given in Table 7-1.

Technology: Process and equipment: The process of salt iodization involves mixing salt with a premixed quantity of iodine to ensure the desired dosage of iodine in the salt. Three processes commonly used for iodating salt are described by Mannar and Dunn (1995), these include: dry mixing of an iodine source or premix, drip feed addition of an iodine compound to salt, and spray mixing of an iodine solution to salt.

(a) Dry mixing

A premix of potassium iodate and an anticaking agent like calcium carbonate, tricalcium phosphate, or magnesium carbonate is prepared in a ratio of 1:9. One part of the stock mixture is then mixed with 10 parts of salt and the premix is introduced into a "cement" mixer or screw conveyor at a prefixed rate. Salt is also introduced into the drum or conveyor. Mixing takes place as the drum rotates or the material moves through the conveyor. This process is suitable for dry powdered salt only. Dry mixing is widely adopted in several countries of South and Central America like Argentina, Bolivia, Guatemala, and Peru as well as Pakistan.

(b) Drip feed addition

Drip feed addition is commonly used for iodization of salt crystals. The salt crystals are fed onto a hopper that discharges at a uniform rate into a belt conveyor, about 35–40 cm wide and 5.5 m long inclined at a slope of about 20 degrees. The conveyor is equipped with a tensioning device. The feed hopper has a capacity of about 300 kg and the rate of salt flow onto the conveyor is controlled by means of a slide valve.

The KIO_3 solution is stored in two 200-litre polyethylene stock tanks with discharge valves at the bottom to permit the filling of two 25-litre feed bottles mounted in such a way as to ensure a continuous circulation of solution from the main tank to the feed bottle. Thus, the solution continuously drips at the desired rate onto the salt crystals. The iodated salt falls into a discharge hopper from which it is collected in bags. Experience has shown that a capacity of 5 tons/hour is ideal for a drip feed system, which requires only a low-pressure head to maintain

Table 7-1. Sample calculation for fixing the level of iodization in salt.

Assuming that the requirement of iodine is 200 µg/day and the salt consumption is 10 g/day.	
Level of iodine required is 200 / 10 = 20 µg/g of salt or	20 ppm (parts per million)
Compensation for transit and storage losses	20 ppm
Fixed level of iodization required	40 ppm iodine = 40 x 1.685[a] = 67 ppm KIO_3

[a]The ratio of molecular weight of KIO_3/I_2 i.e. 214/127 = 1.685. Source: Mannar and Dunn (1995).

the required flow rate. This method is adopted in some Asian countries like Indonesia.

(c) Spray mixing

Salt received in crystal form is crushed into a coarse powder in a roller mill and fed into a feed hopper fitted with a wire mesh screen or a grating at the top to prevent large lumps of salt from falling into it. A second shaft with four plates is fitted in the outlet of the hopper and regulates the flow onto an inclined conveyor belt. Both these shafts are driven by a variable speed drive system and the rate of rotation is adjusted to give the required throughput.

The sheet of salt from the belt discharging into the spray chamber receives a fine atomized spray of KIO_3 solution from two specially designed nozzles at a pressure of 1.4 kg/cm^2. The spray nozzles are designed to deliver a flattened spray that spreads over the entire width of the salt stream. The spraying chamber is provided with a viewing window. The concentration of solution and the spray rates are adjusted to yield the required dosage of iodate in the salt. The iodate solution is kept under pressure in two stainless steel drums each of about 80 litres capacity. The pressure in the drums is maintained by an air compressor equipped with a regulator.

The salt along with KIO_3 falls into a screw conveyor 20–25 cm wide and 2.5–3.0 m long. As it travels through the screw, uniformity of mixing is ensured. The screw conveyor discharges into twin outlets where bags are kept ready for filling. The plant can also be made mobile for operational convenience. A spray mixing type of plant built to UNICEF specifications operates at 6 ton/hour or about 12,000 ton/year. This method is increasingly preferred.

A batch-type version has been developed in India for small-scale manufacturers who cannot afford or do not need continuous spray mixing plants. It consists of a ribbon blender fitted with an overhead drip or spray arrangement. A preweighed quantity of salt is fed into the blender. The blender is operated and a prefixed quantity of iodate is sprayed through overhead nozzles using a hand pump or compressor as mixing proceeds. After iodization the batch is discharged and packed. It is simple to operate in the capacity range of 0.5–3 ton/hour. It is already being used in Bangladesh, India, and Vietnam. It may also be relevant in several other countries where there is need for installation and operation of small iodization plants close to salt production sites or at strategic points in the distribution network.

Table 7-2 shows a comparison of the different iodization methods with their relative advantages and restraints.

Status: Full-scale production.

Product: The addition of iodine to salt (as potassium or sodium iodide/iodate) does not impart any colour or odour to the salt. Iodized salt is not distinguishable from noniodized salt and is fully acceptable by consumers.

Quality aspects: The physical characteristics and chemical composition of the salt vary widely depending on the process of manufacturing, composition of the raw material brine/salt, and refining methods adopted. Salt for iodization should at least conform to the specifications as recorded in Table 7-3.

Samples of freshly made iodized salt should be collected at regular intervals and analyzed to determine the iodine content. Corrective measures should be taken, if needed, by adjusting the flow of salt and/or spray. Iodized salt should be collected into bags directly as it flows out of the chutes instead of allowing it to fall on the ground. As the crystals will still be moist from the spray, they may pick up dust and dirt. Personnel should be advised not to step or walk on iodized salt.

Iodization equipment should be built of stainless steel and regularly maintained and cleaned from salt particles. Mainte-

Table 7-2. Comparison of principal salt iodization methods.

Criterion	Method	Dry mix	Drip	Spray
Salt type	Refined dry powder	+++	++	+++
	Unrefined dry powder	+++	++	+++
	Unrefined moist powder	++	++	++
	Unrefined dry crystals	+	++	++
	Unrefined moist crystals	+	+	+
Cost	Capital outlay	High	High	Medium
	Operating	High	High	Medium
	Cost to consumer	High	High	Medium

Note: + = not recommended, ++ = reasonable, +++ = good. (For a flow chart of salt iodization see Fig. 4.1c in Chapter 4.)
Source: Mannar and Dunn (1995).

Table 7-3. Minimum specification of salt for iodization.

Constituent	Wt%
Sodium Chloride (as NaCl)	98.0
Calcium (as Ca)	0.2
Magnesium (as Mg)	0.1
Sulphate (as SO_4)	0.5
Insolubles	0.5
Moisture	3.0

nance painting is vital to protecting equipment built of mild steel (carbon steel) from saline corrosion. This will involve surface preparation and subsequently covering with a proper coating.

Marketing/distribution channels: In most countries, the salt-producing units are concentrated in a few areas. Often, the iodine-deficient areas are widespread and lie at considerable distances from the salt-production centres. Salt moves from production centres to consumption sites by different modes of transport. Distribution patterns are complex and erratic. Under these circumstances it will be difficult to regulate a dual market comprising iodized and noniodized salt or a target program aimed at iodization of salt for the endemic areas. The only long-term solution in most cases is universal iodization of all salt produced for human and animal consumption.

Cost effectiveness: Suitable equipment and techniques are available at relatively low cost and can easily be integrated with any existing salt-crushing or refining system. The incremental cost of salt iodization, including materials, labour, and amortization, is rather low and estimated at US$0.6–1.9/ton, which is less than 8% of the retail price of salt in most developing countries (see Table 7-4). Assuming a yearly consumption of 5 kg of salt per person, the additional cost of salt iodization then would be 3–10 US cents/person per year. Based on 1992 costs of materials and services in some Asian and African countries, a 20,000 ton/year continuous spray-mixing iodization plant is calculated at about US$ 8/ton. The capital and operating cost for a 4,000 ton/year batch spray-mixing iodization plant works out at about US$12/ton.

Project/program evaluation: In many countries salt iodation programs have been successfully implemented.

Observations: In the less-developed countries, where the available salt is of uneven purity and humidity, and packaging material is often inadequate, the preferred production method is crushing the salt and iodizing it by spray-mixing using KIO_3. Dry mixing of salt with potassium iodate is only possible if the salt is dry and finely ground. Otherwise, the KIO_3 will segregate and settle at the bottom of the container. The drip-feed system is the simplest and cheapest. When the particle size of the salt is very fine (less than 2 mm), however, the drip-feed system is unsuitable because it does not disperse the iodate solution with sufficient uniformity. For national IDD control programs, it may be necessary to import potassium iodate. Alternatively, if the country's requirement is large (at least 30 ton/year), it will be cheaper to import elemental iodine and convert it to potassium iodate (see Appendix 1).

Future requirements/developments: In the case of small-scale producers, either they should set up individual small-batch iodization plants or form cooperatives for a centralized iodization and packing (UNICEF 1994). The feasibility of developing portable iodization units that could be moved from one field to another should also be considered. It is recommended to demonstrate iodizing units by using photographs, slides, or videos.

WATER

Countries: Burkina Faso, Central African Republic, some Central Asian Republics, Italy, Mali, Senegal, and Thailand.

Organizations and groups involved: Ministry of Health and Water and Standard Departments of local governments.

Table 7-4. Estimation of total costs of salt iodization in developing countries.

Cost component	Range (US$/ton)	Average (US$/ton)
Chemical (KIO_3)[a]	0.50–1.30	0.90
Processing	2.35–5.50	4.00
Extra packing material (if required)	0.00–4.00	–
Administrative overheads	0.60–1.50	1.00
Amortization	0.50–2.50	1.50
Total cost of iodization	3.95–14.80	7.40
Retail price crystalline salt	250–1,000	625
Cost of iodization as a percentage of retail price	1.6–1.5%	1.2%

[a]Iodine: range of 40-100 ppm @ US$30/kg.
Source: Mannar and Dunn (1995, p. 70).

Target group: The potential of using community drinking water as a carrier of iodine has been of interest for several decades. Experimental systems for iodizing town and school water supply systems have been tried in Sicily (Italy), Malaysia, Mali, Thailand, and the Central African Republic.

Vehicle: Drinking water.

Fortificant: Iodine crystals.

Fortification level: The objective is to provide an iodine concentration of 50–200 μg per litre of water.

Technology: Process and equipment: Iodization of public water supplies is achieved by diverting a small amount of water through a canister containing crystals of iodine and reintroducing the iodized water into the main water flow. In Thailand, an iodine solution is prepared in small dropper bottles and distributed to schools and households in the endemic areas for direct addition to drinking water in a jar. School water supply systems are fitted with iodine-dosing pumps.

During the last 5 years, a major initiative has been made by the French company Rhone-Poulenc in the development of a technology for adding iodine to drinking water in tubewells. The method involves placing an iodine–silicone polymer in a basket at the bottom of the tubewell, which releases iodine slowly or diffuses into the water uniformly over 12 months, after which the basket is replaced.

Status and results of the field trial: The iodization of drinking water has been shown to be effective in improving iodine status but has not yet been adequately field tested for operational effectiveness.

Cost and cost effectiveness: Water iodization has met with limited application because of high capital and operating costs. As in the case of iodized oil distribution, large investments in human and material resources for water iodization programs may risk diverting attention and resources from the initiation or strengthening of salt iodization strategies.

Project/program evaluation: After tests with the Rhone-Poulenc method in tubewells in rural Mali, urinary iodine levels and goitre prevalence showed significant improvement.

Observations: There is no documentation of pilot projects in water iodization with diffusers. Some of the practical constraints in programs of community water iodization will likely include the following (Mannar and Stone 1993):

- In addition to tubewells, rural populations may have other, preferred options for noniodized drinking water, e.g., streams, rainwater collection, and open wells.
- The amount of polymer required for a tubewell diffuser system has to be calculated in terms of the average water consumption per person and the average number of persons using each well. Determination of the appropriate dose for each well requires preliminary study. It will, therefore, be difficult to estimate variation in water iodine values (for different draw rates from the wells) and the corresponding variation in iodine intake.
- Because the dose of iodine delivered by the diffusers varies at each waterpoint, a monitoring system to assess the efficacy of the intervention will be complex. Routine monitoring of iodine levels in water from all tubewells in all villages would be costly, whereas monitoring on a sampling basis risks giving misleading results.
- The silicone–iodine polymer in the canister inserted in the tubewells has to be replaced annually. The CAR figures indicate a cost much higher than oil capsules.
- Even with community cost-recovery schemes, it is questionable whether beneficiaries will be willing to pay on a permanent basis for iodized water, especially as the problem becomes less visible with goitre regression. It could be an option in certain isolated areas.

Future requirements/developments: Large-scale water iodization programs are planned or under implementation in Mali and CAR. In Burkina Faso, Rhone-Poulenc is working with local firms to make the iodine–polymer system directly available to communities. In Senegal, the government is working with UNICEF to integrate iodization with a water supply and guinea worm eradication project.

Water iodization could be an effective complementary measure where problems with salt iodization persist or as an additional intervention in water supply programs with strong community participation and health education components. Experience in Thailand shows that its feasibility may be in institutional settings such as schools where tubewells or storage tanks with water distribution systems exist. The feasibility of using the canisters in school water supplies could also be tested.

The operational requirements of ensuring an uninterrupted supply of polymer systems to deficient populations and effective coverage of affected communities with iodine have yet to be addressed. Examples of such issues are community sensitization, determination of program responsibilities at the community level, training for installation, cost recovery and supply, monitoring, and compliance.

OTHER VEHICLES

Some experiments with iodization of other foods is discussed in the following. These have limited application and are of minor programmatic importance. For some, only limited information is available.

Bread iodization

Abstract: In 1966, the wheat flour used for bread in the island of Tasmania, South Australia, was fortified with potas-

sium iodate at a level of 2 ppm. Based on estimates of bread consumption, average daily iodine intakes in various age groups were: 81 μg (age 1–3 years), 187 μg (age 7–11 years), and 270 μg (age 15–18 years). The enormous variability in bread consumption implies an unevenness in iodine intakes (Clements et al. 1970).

Other iodized foods

Brick tea: Brick tea is fortified with iodine in Tibet and West China.

Sweets: Trials to fortifiy sweets have been carried out in the Middle East.

Sugar: Sugar iodization has been tested in Sudan but has apparently been abondoned because, even though Sudan rations and controls its sugar distribution, a huge black market for sugar flourishes, leading to both a sugar shortage in western Sudan where IDD is endemic and a sugar oversupply in Khartoum and neighbouring provinces where IDD is not a problem.

Iodine in milk

Abstract: The iodine content of milk is influenced primarily by the exposure of dairy cattle to iodine through water, forage, feed, feed supplements, salt blocks and veterinary medications, and by the exposure of the milk to iodine contamination from iodophor sanitizing solutions directly used as desinfectant on cattle as well as on milking equipment, vats, and other milk containers in the dairy industry. Variability of these practices may result in a variation of iodine concentrations in milk. Some seasonal and perhaps regional variation in iodine concentration in milk may reflect the amount of indoor feeding (i.e., iodine-supplemented feed) during the colder months versus outdoor feeding during the warmer months. Milk available in the US supermarkets is usually pooled from several local dairy farms. High iodine concentrations in milk from one farm will be diluted by lower iodine concentrations in milk from other farms. The iodine content of milk available to the US public appears to be relatively stable with an overall mean of 23 (±9) μg/100 g. One cup of milk (56 μg/100 g) in this case covers for 37% of the RDA for adults. Continued monitoring is needed to ascertain that the iodine levels are adequate and appropriate (Pennington 1990; Nestel 1993).

SINGLE FORTIFICATION WITH IRON

Iron fortification is generally considered to be a long-term approach to combating iron deficiency anemia, as it reaches all segments of the population, it does not require the cooperation of individuals, or an effective system of health delivery, and it costs less. While iron-fortified foods increase iron intake of all individuals consuming such foods, because of very high requirement during pregnancy, there will still be a need for iron supplementation. The success of iron fortification to combat iron deficiency depends on many factors — mentioned in the previous chapters — such as iron compound and food vehicle selected, and the acceptability of the fortified product by the consumers. The following will briefly review some of the vehicles used to carry iron.

WHEAT FLOUR AND BREAD

Countries: A wide range of developed and developing countries all over the world.

Organizations and groups involved: WHO; FDA, FNB-NAS-NRC, CFN-AMA (USA); the Panel of Iron in Flour (MOH), MRC (UK); MRC, SCFAR, SARCDC (Sweden); School of Public Health, Institute of Public Health Research, Tehran University, Iran.

Target group: Whole population, especially anemic men and women, menstruating women, pregnant women and children, even in populations with high standards of living.

Vehicles: Flour is considered the ideal vehicle for iron fortification in countries with cereal-based diets. Cereals (wheat, maize, or rice) most often provide the largest single source of calories and are relatively inexpensive. They are often milled in a few places in a country and are widely consumed, irrespective of age, sex, and socioeconomic status. Moreover, there is no risk of overconsumption. For wheat, the amount of iron added is designed to restore the iron lost in milling (milling removes about two-thirds of the natural iron content of a cereal) or to enrich the flour. Nevertheless, considering the inhibitory effects of cereals on iron bioavailability, fortification of cereals may not be the most efficient way for reducing iron deficiency anemia.

Fortificants: Hallberg et al. (1989) gave two requirements for an iron fortificant in flour: insolubility in water (due to high water content of flour) and good bioavailability in humans. Schricker and Miller (1982) state that solubility under gastric conditions is required to obtain an availability similar to that of the native iron in the meal.

Iron salts: Easily soluble iron compounds, such as ferrous sulphate, ferrous fumarate, and ferrous gluconate in flour, are readily available for absorption but can dissolve during storage. These ferrous iron salts may be oxidized to form coloured ferric oxides. Iron salts induce rancidity in flour on storage (by catalyzing lipid oxidation reactions). Encapsulated ferrous sulphate seems to have even more inferior storage properties than reagent grade ferrous sulphate. Iron salts also have a harmful effect on baking qualities. In the latter case, the particle size of iron salts is important.

In Britain, the addition of ferrous sulphate and ferric ammonium citrate to flour is allowed and, in the USA, ferrous sulphate is routinely used. In some studies, ferric orthophosphate, ferric sodium EDTA, sodium iron phosphate, and iron pyrophosphate are used. The less-soluble iron salts have the least functionality problems, but their bioavailability is also less.

Searching for an iron source that can be absorbed better, Hallberg et al. (1989) found a microcrystalline complex ferric orthophosphate (CFOP, $Fe_3H_8(NH_4)-(PO_4)_6 \cdot 6H_2O$) to fortify flour for bread rolls. CFOP is added in the range of 2–14 mg/meal (Hallberg et al. 1989).

Elemental iron powders (reduced iron): Elemental iron powders are extensively used for fortification of flour. They are chemically more inert than iron salts and induce fewer technical problems. Storage properties of reduced iron are much better than iron salts. The greyish powder may cause off-colour problems, but these are not very serious. Elemental iron can be obtained by the following processes:

1. High temperature reduction of ground iron oxides with either hydrogen or carbon monoxide;
2. Reduction by an electrolytic deposition process. This product is purer than the former and has a somewhat smaller particle size; and
3. Decomposing iron pentacarbonyl (produced by reacting iron with carbon monoxide) to carbonyl iron (and carbon monoxide gas). This process provides probably the finest iron particles.

For iron availability, the small particle size and acid solubility of reduced iron seem to be important factors to be considered.

Other iron sources: On page 51, a haem iron concentrate of bovine blood used for iron fortification of biscuits is mentioned. Johnson et al. (1985) suggest using soybean hulls for iron fortification in bread. The hulls are low in oil so rancidity should not be a concern and they contain negligible quantities of phytic acid, which is frequently the plant component associated with poor mineral availability. Soybean hulls are considered a by-product of soy processing.

Fortification level: The maximum ferrous sulphate addition in flour for bakery products is 40 ppm. The standard set by various countries are: Canada, 29–43 ppm; Chile, 30 ppm; Denmark, 30 ppm; Guyana, 29–36 ppm; Kenya, 29–36 ppm; Nigeria, 35 ppm; Sweden, 25–75 ppm; UK, 16.5 ppm (mg/kg flour, this means restoration of 80% extraction); the US increased iron fortification in 1982 from 28–36 ppm to 44 ppm; and Zambia, 29–36 ppm. Not all countries that have set fortification standards have made fortification mandatory.

Soybean hulls can be added to bread at 5% flour replacement without deleterious effects on baking performance and overall acceptability. Five percent replacement would cause an iron level of 1.9 mg/100 g bread, which is 68% of the iron required by the US Food and Drug Association (FDA) (Johnson et al. 1985).

Technology: Process and equipment: The technology of iron fortification in whole-grain wheat is comparable to fortification of rice. Fortification of wheat is normally done either at the mill or at the bakery. Figure 7-1 shows a flow chart illustrating flour milling steps and point at which fortification takes place. The addition of iron can be performed in a continuous process using a feeder or in a batch process by hand. For the latter, compressed tablets are available for specific sizes of dough. Because iron fortification of flour is usually performed with other fortificants, (commercially available) premixes are often used. The addition of premixes to flour is described in Chapter 8. Stability problems inhibit ferrous sulphate being mixed with wheat flour to form a concentrated premix.

Reduced iron may be entrapped by the magnet used to remove tramp metals from incoming flour. Unlike iron salts, reduced iron is magnetic. Tests did not show significant differences in iron content or segregation of the flour and the reduced iron before and after magnetic treatment. The addition of reduced iron to less-fine milling products like farina, semolina, or grits may cause segregation problems, especially when the fortified product is run through a purifier to remove dust.

Status and results of field trials: Fortification of bread with iron seems to be an effective and safe method to prevent IDA, or even to cure its mild forms. A lot of laboratory and field studies are performed on the bioavailability of iron in bread. Several field projects do report positive effects of fortification of bread with iron. The iron deficiency rate in Sweden has been reduced from about 25–30% to 7% when the fortification program started. About 40% of the iron consumed in Sweden and 20% of that in North America comes from fortified wheat flour and bakery products.

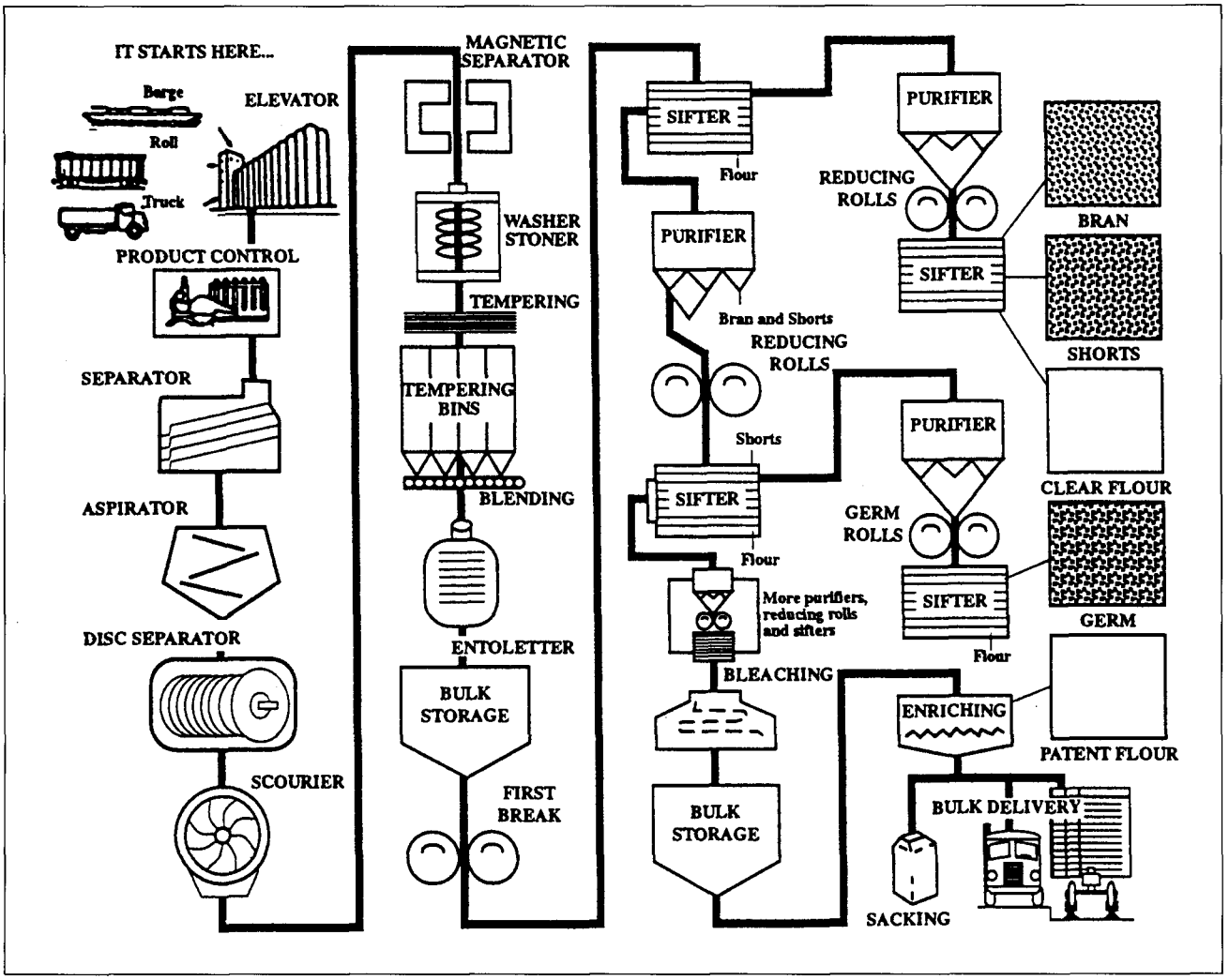
The present level of iron restoration or enrichment of flour for the use of bread in Britain and the US, however, is not sufficient for several population groups, particularly females in the age group of 9–54 years and children under 6 years of age. Also, the decreased cereal consumption (in the US) has partly been responsible for this insufficient iron intake. Fortification with CFOP and soybean hulls is reported only on a laboratory scale.

Product: Addition of iron in the used amounts does not seem to affect the bread quality.

Quality aspects: The maximum ferrous sulphate addition in flour for bakery products is 40 ppm, and the fortified flour should not be stored for more than 3 months at moderate temperature. Not much is said about iron quality apart from the level of iron fortification. The US requires the form of iron that is harmless and assimilable. Canada requires the particle size of 95% of the reduced iron <44 μm, and at least 90% solubility in 0.1 N HCl.

An iron-fortification program requires periodic analyses to ensure that iron is in the food in the desired amounts. Method 40–40 of the American Association of Cereal Chemists (AACC) is a qualitative method that roughly determines the type of iron used in fortification. By adding a drop of a reagent, large red

Fig. 7-1. Flow chart of flour milling and point of fabrication (source: Nelson 1985).



spots rapidly appear if ferrous sulphate is present, little red spots appear after about 10 minutes if reduced iron is used as the iron source.

To measure iron quantitatively, extraction is necessary before detection. For extraction, one can perform dry-ashing, which has problems with sample loss, volatilization, iron contamination, or wet-ashing, which is more dangerous because of the use of hot, concentrated, oxidizing acids. For detection, colorimetric procedures can be performed or atomic absorption can be used (e.g., AACC method 40–41A), which can detect several minerals in the same sample but this is more expensive.

Marketing/distribution channels: When milling is centralized and distribution of flour and bread can be controlled adequately and accurately, enriching bread (in developing countries) would be simple. If the use of dried yeast becomes the rule, and all bakers are obliged to use it, this leavening agent could serve as the vehicle for enrichment (Vaghefi et al. 1974). Moreover, yeast has a positive effect on iron bioavailability.

Cost and cost effectiveness: The easiest available and by far the least expensive iron source is ferrous sulphate heptahydrate. In Appendix 2, some estimated costs of commonly used iron sources are given. Although ferrous sulphate heptahydrate is not included in this table, it is much cheaper than dried ferrous sulphate. Ferric ammonium citrate and ferric pyrophosphate are extremely expensive.

Barrett and Ranum (1985) indicated the cost for ferrous sulphate in amounts sufficient to add 38 mg iron/kg at US$0.015 for 100 kg flour. They estimated the cost of a fortification program in Egypt where providing 9 mg iron/day to every person would cost US$0.015/person per year. If the same effect would be obtained with iron supplements tablets, the cost of the tablets alone would be US$0.11/person per year. The price of the iron compound itself is always a very small part of the overall price of the product.

Project/program evaluation: Effective fortification programs have been implemented under strict government supervision and after proper legislation has been passed.

Observations: Iron fortification often goes hand in hand with fortification with niacin, thiamin, riboflavin, calcium, vitamin A, pyridoxine, folic acid, magnesium, and zinc. Because the addition of vitamin A to flour and bread started in the US only in 1982, a lot of research has been done on single iron fortification.

Bioavailability of different iron sources: Elwood et al. (1971) found that the bioavailability of iron salts eaten with bread is much lower than has been suggested from highly controlled radioactive isotope studies. Lee and Clydesdale (1980) report that iron sources when added to flour and baked as biscuits or bread do not remain in the original chemical form. The net effect of the baking process seems to be the formation of insoluble forms of iron. An exception is made for ferric sodium EDTA. The availability of the iron in soybean hulls seems to be equal to the commonly used ferrous sulphate (Johnson et al. 1985). The relative bioavailability of CFOP varied from 30 to 60% when wheat rolls were served with different meals (Hallberg 1989).

Circumstances that affect bioavailability of iron in bread/flour: The relative availability of nonhaem iron in bread seems to be affected by several factors. There are many substances in a normal diet that interfere with iron absorption:

- ***Composition of the meals:*** Studies in which bread is eaten alone are not representative of real life situations.
- ***Iron status of the individual:*** Iron deficient subjects absorb a larger percentage than healthy subjects do, and if less iron is available, absorption seems to be more efficient.
- ***Presence of inhibitors in food:*** Bran content of the flour and bread. Bran components inhibit iron absorption (Brune et al. 1992). So a lower extraction rate of flour (with a higher content of bran) causes less iron absorption. This was also confirmed in experiments on the absorption of ferrous sulphate in fortified Egyptian flat breads compared to European breads (El Guindi et al. 1988). In animal experiments, Ranhotra et al. (1979) found no inhibitory effect of adding cellulose to bread (to make high-fibre bread) on the availability of iron in bread.
- Ascorbic acid is known as an enhancer for iron availability, but its addition to flour or bread is not useful. The high temperatures required for baking cause oxidative destruction of the ascorbic acid. The pH conditions during fortification can also affect the proposed enhancing effect of ascorbic acid (Sayers et al. 1973; Derman et al. 1977; Clydesdale and Nadeau 1985; Hallberg 1986).

El Guindi et al. (1988) found positive effects on iron absorption if EDTA was added. Also Whittaker and Vanderveen (1989) report a higher availability of iron when Egyptian flat bread is fortified with $FeSO_4$+Na_2EDTA or NaFeEDTA instead of $FeSO_4$. This is due to the chelating effects of EDTA.

The chemical change of iron compounds to insoluble forms during baking as mentioned earlier is not seen with NaFeEDTA. The enhancing effect of EDTA is not endorsed by all scientists (Ranum and Loewe 1978) and seems to be the opposite when the ratio EDTA:Fe > 2:1 (Hurell 1984):

- ***Processing method:*** The processing effects are not very clear; El Guindi et al. (1988) and Hallberg et al. (1986) did not find an effect of the baking process on the relative availabilities of nonhaem iron in breads and meals. As mentioned, Lee and Clydesdale (1980) found an effect of the baking process in which almost all initial iron forms changed into insoluble forms of iron with equal availabilities. Potassium bromate, a maturing agent added to flour at the mill, can react with ferrous sulphate and produce Fe^{3+} (Lorenz 1982). Schricker and Miller (1982) suggest an enhancing effect of heat and pressure on iron availability. The water concentration in the baked product during this process might hydrolyze the phytate causing the enhancing effect.
- High levels of salt in bread may decrease, whereas high levels of yeast may increase, iron availability in bread (Kadan and Ziegler (1986).

Future requirements/developments: There is an urgent need to discover or develop an iron preparation that is more readily available or that can be added to flour in relatively high concentrations without seriously affecting its storing or baking qualities. There might be a future for CFOP, bovine haem concentrate, and/or EDTA-containing compounds.

MILK AND MILK POWDER

Countries: Australia, Canada, Chile, India, Jamaica, Mexico, USA, Yugoslavia.

Organizations and groups involved: International Atomic Energy Agency; National Institute of Arthritis, Metabolic,and Digestive Diseases; Dairy Council of California; National Dairy Council; Nutrition Foundation; Chilean Ministry of Health; The Consejo Nacional para la Alimentacion y Nutricion; United Nations University; Departamento de Investigacion y Bibliotecas de la Universidad de Chile; the Nestle Nutrition Research Grant Programme; Hoffmann-La Roche and Co. Ltd.

Target group: Infants and young children.

Vehicles: Cow's milk, liquid milk, dry skim milk (DSM), full cream milk powder, buffalo milk.

Fortificants: The main iron source used is ferrous sulphate, but all iron sources mentioned in Appendix 2 are eligible. Enrichment of iron-fortified milk with ascorbic acid improves iron bioavailability. Roughly 5–10% of iron in fortified milk is absorbed. Ferric orthophosphate seems to have poorer bioavailability than ferrous sulphate, electrolytic iron, or carbonyl iron. The bioavailability of ferrous chloride was found

to be better than ferric lactobionate. Addition of zinc does not affect bioavailability of iron in milk. Results about the effect of milk products themselves on iron availability are contradictory. An inhibiting effect of milk is sometimes suggested, which might come from milk fat and not from low fat milk products (Ashworth and March 1973; Momčilovič and Kello 1979; Ranhotra et al. 1982; Rivera et al. 1982; Hurell 1984; Galan et al. 1991).

Addition of iron to dairy products can cause lipolytic oxidation, resulting in "oxidized" flavours and odours. Iron chelates are less susceptible to oxidative rancidity than ferrous salts, although ferrous sulphate causes much more rancidity than, for instance, ferric ammonium sulphate and ferric ammonium citrate.

Heating decreases the oxidative effect of ferrous sulphate and increases the oxidative effect of iron chelates as ferric nitrilotriacetate and ferric lactobionate. But after heating, iron chelates are less susceptible to oxidative rancidity than ferrous salts.

Fortification level: Unfortified milk contains less than one ppm of iron. In most studies, fortification levels of 10–25 mg iron/l (reconstituted) milk are employed, although sometimes fortificant at the level of 100–125 mg iron/l is studied. Ascorbic acid is added at the level of 50–100 ppm.

Technology: Process and equipment: The main problem in fortifying milk powder with iron is the required sophisticated packaging. In principle, the technology is simple and it is not very expensive to fortify regular milk powder available in developing countries with ferrous sulphate. The oxygen-free packaging, however, necessary to prevent rancidity, makes fortification complicated and expensive. To prevent oxidation as much as possible, iron fortification of milk is recommended after homogenisation (emulsification of milk fat, which is of great influence) and just before pasteurization (Hegenauer et al. 1979a,b; Kiran et al. 1977).

Status and results of field trials: Iron deficiency can be prevented by programs distributing iron fortified milk (Rivera et al. 1982; Stekel et al. 1988a,b; Olivares et al. 1989). In Chile, the National Program of Supplementary Feeding is involved, but most often studies are at laboratory or field trial levels.

Product: It is possible to formulate iron fortified milk with good organoleptic acceptability. Stekel et al. (1988b) found good acceptability of powdered full-fat milk with ferrous sulphate (15 mg/100 g) in the presence of ascorbic acid (100 mg/100 g). Saini et al. (1987) did organoleptic research and found that an addition of up to 20 ppm ferrous sulphate or ferric ammonium citrate added to buffalo milk is acceptable. If the iron level is further increased, off-flavours develop. Boiling can improve the flavour of fortified milk, probably because the cooked flavour masks the oxidative rancidity.

There is little information on the storage stability of iron fortified milk. Fortified pasteurized milk can only be kept for a few days, during which some off-flavours often develop due to oxidative rancidity. Rancidity in milk powder is not described extensively. In some studies, the iron source is added to the milk or reconstituted milk just before consumption, so stability is no problem. The full-fat milk powder in the Stekel et al. (1988a,b) and Olivares et al. (1989) studies was fortified with ferrous sulphate. Because packaging in oxygen-free containers was not possible locally, rancidity occurred.

Cost and cost effectiveness: Switching from unfortified to a fortified milk, like in the program in Chile (about 13 million kg of dry milk are distributed each year to infants), means an increase in price of about 13–14%. Of this, only about 1% is contributed by ferrous sulphate and ascorbic acid and the rest by the increased cost of packaging (see the discussion in Hurell (1982)).

INFANT FOODS/FORMULAS

Countries: A wide range of countries all over the world, both in developed and in developing countries. Iron fortified infant food is available around the world.

Parties involved/cooperation: PAG, UNU/WHP, TPI, INACG, ILSI, HNI, AAP/CN, CPS, ESPGAN; USDA/ARS, USAID, FDA, PHS, NIH, NDC (US); CMAFP (UK); FPR, FCR (Finland); AEB, CT (South Africa); IAEA; MRC; FFWF (Austria); CPHIIF, MOH, INTA (Chile); CONICET, SECYT, UBACYT (Argentina); NNRGP (Switserland); Mead Johnson Nutritional Group (US); Bristol-Myers International Group.

Target groups: Infants and pregnant and lactating women. Because of the expansion of blood volume and extremely rapid growth during infancy and early childhood, infants are the most critical population group regarding iron deficiency. After about 4–6 months, the neonatal iron stores are depleted and additional iron is essential, particularly up to 24 months.

Vehicles: Breastfeeding is recommended as the best infant food, and exclusive breastfeeding should be encouraged for all infants up to the age of 6 months. Thereafter, because of increased demand for higher energy and iron for growth in children over 6 months, breastmilk should preferably be supplemented. Infant cereals have been used to supplement breastfeeding well after 6 months when the older infants' diet should be supplemented with some solid foods.

The distinction between infant formulas and infant cereals is not evident, and they are often made with the same ingredients. Infant formulas are more liquid and not designed for addition to milk, whereas infant cereals meet the solid food requirement, are usually dry, and most are designed to be added to milk. No cow's milk is recommended before the age of one year. It contains little vitamin D and iron and can cause occult blood loss. Instead, infant cereals are preferred. The use

of soya as an ingredient is often recommended to avoid allergies to cow's milk. Soya flour products have a high native iron content, so when soya flour is used, the processed food will have a higher iron content than the other flour-based infant cereals.

Infant cereals were mainly designed for weaning infants but also for risk groups such as pregnant women, lactating women, and children in developing countries. They generally consist of a cereal (wheat, rice, maize, and sorghum), a high-quality protein compound (soybean, nonfat dry milk, and whey) and a fat component. Vitamins and minerals are added for fortification, and sugar may be added for flavouring. Local ingredients should be used as much as possible. The result is a nutritionally improved formula compared with any of the single ingredients.

The ingredients may be milled and processed like heat treated, rolled, parboiled, or extruded. The final product for consumers is sold as a drink or as a dry powder to be cooked like rice (Barrett and Ranum 1985). A typical composition of the widely used infant cereal, corn–soy-milk (CSM), is shown in Table 7-5. Table 7-6 gives the protein sources of several widely used infant cereals.

Fortificants: Ferrous sulphate (heptahydrate, reagent grade) is by far the most commonly added iron source to both liquid and powdered milk and soy-based infant formulas, especially in the US and Canada. It can sastifactorily be used in infant formula and other foods that do not contain reactive forms. Fat oxidation and discoloration are common problems using ferrous sulphate, so research to use encapsulated ferrous sulphate is ongoing.

Infant cereals are not compatible with ferrous sulphate and, therefore, small-particle elemental iron is usually added. Sodium iron pyrophosphate was commonly used in cereals but has been replaced due to its low bioavailability (Hurell 1984; Purvis 1985; Rees et al. 1985).

Ferrous fumarate is often used because of its reddish brown colour, which is compatible with the yellow and brown colour characteristics of the CSM, WSB, and other blended foods. Ferrous succinate seems to be just as suitable as ferrous fumarate, without causing fat oxidation or discoloration (Hurell 1989).

In Europe, iron EDTA is widely accepted for iron fortification. A wide range of other iron sources are also used: ferrous citrate, ferrous lactate, and ferric ammonium citrate might be used in liquid formula. Ferric citrate and ferric gluconate might be used in liquid soya formula. Ferric pyrophosphate, ferric orthophosphate, and saccharated ferric oxide are used in infant cereals. Stabilized ferrous carbonate, ferrous gluconate, and ferrous saccharate are other possibilities.

The main technological problem with iron fortification of infant foods concerns colour and off-flavour production. In general, the more soluble the salt, the greater the problem. Addition of ferrous sulphate to liquid milk or soya products darkens their colour. It is possible to fortify milk formulas with acceptable results, but this requires a balanced composition and (most importantly) appropriate packaging. This is possible in industrialized countries, but is not likely to be feasible in small, local industries. Adequate packaging is often a limiting factor regarding production of fortified formulas. Fortification with ferrous sulphate requires the use of oxygen-free sealed cans.

Flavour problems in iron fortification are usually due to fat oxidation. This is especially seen with the cereal products, which contain a high level of readily oxidizable unsaturated fatty acids. Ferrous sulphate and ferrous gluconate are the most important enhancers of lipid oxidation. Elemental iron hardly

Table 7-5. A typical composition of corn–soy milk (CSM) (%).

Maize meal	59
Soybean flour	17.5
Nonfat dry milk	15
Soybean oil	5.5
Iron (as ferrous fumarate)[a]	180 ppm
Ascorbic acid[a]	1,000 ppm

[a]Added among others in a mineral premix (ppm in dry food).
Source: Cook and Bothwell (1984).

Table 7-6. Percentages of total protein contributed by the different major ingredients.

Infant cereals	*Soya*	*Cornmeal*	*Milk*	*Wheat*	*Whey*
Corn–soy-milk (CSM)	45	27	28		
Corn–soy blend (CSB)	63	37			
Wheat–soy blend (WSB)	55			45	
Wheat–protein-concentrate blend (WPC)	61			39	
Whey–soy drink (WSD)	74				26

Source: Cook and Bothwell (1984).

induces off-flavours, if particle size is not too small. Ninety-five percent should be below 44 μ, which seems to be the most suitable in dry infant foods concerning organoleptic properties and bioavailability. Also, encapsulated ferrous sulphate causes little rancidity during storage. On adding ferrous sulphate (even when it is encapsulated) or other iron sources (ferrous/ferric salts with chloride, citrate, or acetate) to infant cereals, a dark grey or green colour develops when (hot) milk is added. The colour development of encapsulated ferrous sulphate is related to the melting point of the coating material and depends on the milk temperature (Hurell 1984).

Addition of haeme iron is also a possibility. Although it is especially suitable for use in meat products, Hertrampf et al. (1990) used a bovine haemoglobin concentrate (BHC) to fortify an infant cereal made by extrusion of rice flour. The main technological problem with BHC concerns the colour. Because of the low iron level in the strongly coloured BHC, the relative high level of 5% has to be added. Also microbiological problems can develop. Extruded rice cereal fortified with BHC was adequate to prevent iron deficiency anemia only if consumed in a dose over 30 g/day. For several infants, the volume was a problem. Another aspect of fortifying (infant) foods with BHC is ethical, cultural, or religious resistance to the addition of blood products to foods.

Fortification level: The Codex Alimentarius sets the minimal iron fortification level for infant foods at 1 mg Fe/100 kcal, which is about 7 mg Fe/l formula. Maximum fortification levels are 3 mg/100 kcal (≈20 mg/l) in the US; 1 mg/100 kcal in the UK, and 1.5–2 mg/100 kcal in France. In the US, if fortification level is raised to over 7.5 mg/serving, the formula or cereal is considered a supplement and no longer is regarded as a food.

In most studies fortification levels are described of about 12 mg Fe/l formula (10–17 mg/l) and 0.15–0.5 mg Fe/g cereal. The US upper limit of 20 mg/l is often related to the use of soy, because soybean isolate has a high and variable native iron content. Lower levels are common in Europe with more efficient use of iron from foods with lower fortification levels, these levels are also sufficient. Decreasing the US level to the European levels, is a main point of discussion. The minimal level to prevent iron deficiency was found to be 7 mg/l by Saarinen and Siimes (1977), which was supported by Bradley et al. (1993). Haschke et al. (1993) found that 3 mg ferrous sulphate/l in a whey-predominant formula is sufficient to protect infants (3–6 months of age) from becoming iron deficient.

BHC is added to extruded rice flour at a level of 5%, the iron in BHC is only 0.28%. (Calvo et al. 1989; Hertrampf et al. 1990). See also Appendix 2 about iron sources and page 50 "Biscuits."

Technology: Process and equipment: Most infant cereals/formulas are produced under batch conditions:

- Preblending of dry major ingredients,
- Separate weighing and addition of vitamins and minerals,
- Blending of the entire batch for uniform distribution,
- Addition of the fat or oil component,
- Final blending, and
- Packaging.

For fortified blended foods, a premix of fortified cereals is also used instead of the separate addition of vitamins and minerals (Barrett and Ranum 1985).

Status and results of field trials: Iron-supplemented infant foods are universally available. In 1985, already 80% of all US formula sold was iron fortified, and this has been credited as the major factor in the declining prevalence of anemia in US infants among both low-income and middle-class populations. Some groups reject iron-fortified formula believing that infants fed iron-fortified formulas are more likely to suffer from gastrointestinal problems. Theories about gastrointestinal problems are the presumed bacterio-static properties of the iron binding proteins of milk (lactoferrin and transferrin). They may lose those properties when full saturation with iron occurs instead of the normal one-third saturation. This is a reason to avoid unnecessarily generous iron supplementation (Saarinen and Siimes 1977). No effects of this kind, however, have been reported, except for stool colour. Even therapeutic doses of iron are well-tolerated by infants (Nelson et al. 1988; Committee on Nutrition 1989; Dallman 1989).

A more important point of disagreement and reason to minimize iron fortification is the effect of iron on the absorption of copper and zinc. The Committee on Nutrition (1989) claims that iron fortification of formulas does not impair the absorption of zinc and copper to a degree that is nutritionally important. But Haschke et al. (1986) found repressed absorption of copper with 10.2 mg Fe/l infant formula and Seely et al. (1972) report that in premature infants, copper deficiency can presumably be caused by iron fortification of infant formula. Effects on zinc absorption are also reported and is a point of controversy. A maximum Fe:Zn ratio of 2:1 might be good advice. In human breast milk, the ratio of Fe:Zn is <1. (Hurell 1984; Haschke et al. 1986; Dallman 1989; Power et al. 1991).

Marketing/distribution channels: Infant foods are either distributed by feeding programs or by sale on the open market all over the world.

Cost and cost effectiveness: See also the section on "Milk and Milk Powder" and "Wheat Flour and Bread."

Project/program evaluation: The feeding of iron-fortified formula to infants has been shown to eliminate overt iron deficiency, the most common cause of anemia in childhood,

almost completely. Iron-fortified infant formulas or cereals are also suitable to maintain adequate iron levels. Supplements to breastfeeding over 6 months of age should also contain additional iron.

Iron fortification should not be considered a separate goal of health and nutritional programs targeted to infant populations. It should be part of a broader strategy to ensure, for example, adequate levels of protein, energy, and other micronutrients.

Observations

Bioavailability: Breastmilk contains small amounts of iron, but this is well absorbed and utilized. About 49–70% of the breast-milk iron (0.66 mg/l) is absorbed by infants. Maximum absorption of cow's milk iron (which is present in levels of 0.1–0.2 mg/l) is 30 %. Only about 3–10% of supplemented iron in infant formulas (about 12.5 mg/l) is absorbed. Iron absorption from infant cereals is even less.

The oxidation state of iron affects the absorption. The iron in foods can exist in ferric (Fe^{+++}), ferrous (Fe^{++}), and elemental (Fe) states. Ferrous iron is more soluble than ferric, especially at higher pH. Iron absorption takes place in the intestine, which has a slightly alkaline environment.

Ferrous salts like ferrous sulphate, -fumarate, -gluconate, -lactate, and -citrate are all seen as highly available, which means they are roughly absorbed by 3–10% on average. Ferric ammonium citrate might also have good bioavailability in humans. The availability of elemental iron is not clear and varies greatly between very poor and good acid solubility, depending on particle size. Phosphate-iron salts show usually poorer absorption. Absorption of BHC in extruded rice cereal is about 14%.

These bioavailability figures for iron sources are definitely not absolute: A lot of research studies contradict one another. Many factors affect absorption, and animal studies are not directly comparable to human studies. Because iron absorption is often less than what is assumed, the intake may not meet the daily requirements. This is especially important in developing countries where iron is not usually provided by different sources as it is in western countries. Simply increasing the iron content may not result in increased uptake. There are many questions concerning the gastrointestinal tolerance and interaction with other minerals. Moreover, simply increasing iron uptake may also be inefficient, because the lower the level of added iron, the more effective absorption occurs.

Factors affecting absorption: Ligands, which chelate iron, can inhibit absorption by forming insoluble complexes or very high affinity complexes (as phosphates, oxalates, dietary fibre, tannins, and phytate) or can enhance absorption by forming soluble chelates with iron, thus preventing precipitation (as amino acids, citrate, and ascorbate) (Hurell 1984). In practice, many chelators do affect iron absorption. The reason for high bioavailability of breast-milk iron is unknown. This higher bioavailability is not due to lactoferrin but could possibly be due to chelating agents.

Factors enhancing absorption: Vitamin C or ascorbic acid found in fresh fruits and vegetables is a strong enhancer of nonhaem iron absorption. This is also true in infant formula, due to the ability of ascorbic acid to form a soluble complex with iron, which protects iron from the inhibitory ligands. Absorption can increase up to six times in the presence of vitamin C. Addition of ascorbic acid to infant foods is common. Stabilized cellulose coated ascorbic acid is often used because it is more resistant to deterioration by moisture and temperature. Ascorbic acid is commonly added at a level of five times the iron content. No other organic acids have such strong enhancing properties (Derman et al. 1980; Rizk and Clydesdale 1985; Stekel et al. 1986; Haschke et al. 1988). Fructose seems to be an enhancer, but other sugars like glucose and galactose, which also form complexes with iron are not, therefore, the use of ferric fructose as source of iron can be considered.

Among sugars, sorbitol, mannitol, and xylose have enhancing properties. Meat and fish enhance absorption of nonhaem iron and haem iron as well. An important role is probably played by cysteine or a typical protein type. The phosphoprotein in egg has been shown to be a strong inhibitor. EDTA and NTA (nitrilotriacetic acid) have chelating properties, with enhancing effects. NaFe EDTA can be used as an iron source and is seen by some as a promising chelator. But if the ratio EDTA:iron is greater than 2:1, EDTA acts like an inhibitor. Because EDTA is often used as a food preservative, inhibition is likely in many foods (Cook and Bothwell 1984; Hurell 1984).

Factors decreasing absorption: Soya products can inhibit iron absorption, but results of research on soya inhibition are often contradictory. Soya may have an iron-binding factor, which does not seem to be dietary fibre or phytates, probably due to partially digested soy proteins. Availability of iron in soy-based or milk-based formulas is not obviously different. Cow's milk has also an inhibitory effect, mainly due to the nature of cow's milk proteins (casein with its strong iron-binding properties via its serine phosphate groups) and the high level of calcium and phosphorus (Stekel et al. 1986; Hurell 1989; Pabón and Lönnerdale 1992). Cereals can inhibit iron absorption. The exact reason is not clear but the inhibitory effect might be due to phytate, phosphate, and/or dietary fibre.

BISCUITS

Country: Chile.

Organizations and groups involved: Instituto de Nutrición y Tecnología de los Alimentos (INTA), Universidad de Chile, Santiago; Departemento de investigación y Bibiliotecas de la Universidad de Chile.

Target group: School children. Supplementary feeding program in Chile; biscuits and milk (substitute) for school children. This program is national in scope, reaches a significant proportion of the nutritionally vulnerable population, and has enjoyed long-standing support.

Vehicles: Wheat-flour biscuits. The composition of iron fortified biscuits is given in Table 7-7.

Fortificants: Haem iron concentrate (HIC), also called bovine haemoglobin concentrate (BHC). Bovine blood from slaughtering operations has an enormous potential as a source of large quantities of haem iron and proteins (see Table 7-8). Iron yield was 0.27% of HIC. The bioavailability of HIC is better than nonhaem-iron compounds, which are generally used in the fortification of wheat flour and its processing products.

Fortification level: Considering technical and organoleptical possibilities, 6% HIC was chosen as the appropriate fortification level. Not only was iron content eight times higher than in the unfortified control samples, protein content was also 1.6 times higher. Bioavailability of hemoglobin iron measured with a double isotope technique showed a haem-iron absorption of 19.7 %. The school children received 30 grams of fortified biscuits a day, during two school periods. This made a daily uptake of 0.96 mg iron (30,000 mg x 6% x 0.27% x 19.7% =0.96 mg iron).

Technology: Process and equipment: HIC is obtained by separating bovine blood into plasma and red blood cell fractions by centrifuging. The blood cells are washed three times with 0.9 % NaCl and are freeze-dried. The use of HIC may produce some microbiological problems, yet the main problem in using HIC for fortification is that because the amount of iron in HIC is low, it is necessary to use high amounts of HIC. This results in a dark colour that, although it is acceptable in biscuits, it is not acceptable in many other foods. It is, therefore, not yet feasible to use this technology for fortification of other foods.

Table 7-7. Composition of control and 6% fortified biscuits.

Composition	*Control biscuits (%)*	*Iron fortified biscuits (%)*
Wheat flour	61.00	55.30
Haem iron concentrate	0.00	5.70
Liquid sugar	28.60	28.60
Hydrogenated lard	9.50	9.50
Vanilla essence	0.15	0.15
Sodium bicarbonate	0.50	0.50
Monocalcium phosphate	0.15	0.15
Antioxidants	0.03	0.03

Table 7-8. Composition of the haem iron concentrate.

Content	*Amount (%)*
Proteins	94.0
Lipids	0.5
Carbohydrates	0.4
Ash	0.4
Iron content of ash	10.0

The process for producing iron-fortified biscuits is as follows:

- Flour, HIC, additives, and antioxidants are dry-mixed;
- Hydrogenated lard and liquid sugar are added;
- The dough is kneaded to a homogeneous consistency;
- It is moulded in an automatic machine; and
- Biscuits are cooked in a continuous horizontal electric oven for 10 minutes at 270°C (Asenjo et al. 1985).

Status and results of the field trial: Serum ferritin values significantly increased by the fortified biscuits, even though the groups of school children had very good initial iron status to start with. The effect of hemoglobin-fortified biscuits in a population with a poor iron status will, therefore, be even more evident. The high-iron bioavailability, the good organoleptic characteristics, and the biological effect on iron nutriture make the hemoglobin-fortified biscuits an appealing alternative to combat iron deficiency. Moreover, HIC is not only an excellent iron source, and its high lysine content improves the protein quality of the biscuits as well (Asenjo et al. 1985; Olivares et al. 1990). Although biscuits with 6% HIC were acceptable in this trial, sensory evaluation showed a preference for the control biscuits that had no HIC. Nevertheless, Olivares et al. (1990) reported an excellent acceptability of both types of biscuits.

Quality aspects: A catalytic effect of the HIC on the lipid auto-oxidation was observed. Under controlled conditions (17–20°C, oxygen and light-proof packaging), the biscuits can be stored up to 7 months (Asenjo et al. 1985).

Marketing/distribution channels: School feeding program.

Cost and cost effectiveness: Bovine haemoglobin is largely wasted during the commercial slaughter operation, particularly in poor countries. Industrial methods to collect and process the blood are both available and are rather inexpensive (Hertrampf et al. 1990).

Future requirements/developments: The biscuit project in Chile seems to provide great opportunities. Technical possibilities of upscaling the HIC production have to be researched and cost analysis should be performed.

RICE FLOUR

Countries: Argentina and Chile.

Organizations and groups involved: CESNI, Buenos Aires, Argentina; and the University of Santiago, Chile.

Target group: When an infant reaches 4–6 months of age, breastmilk alone becomes insufficient to meet the iron requirements of a normal, healthy child. Cereals, traditionally used to supplement breast-fed infants have several limitations, such as low iron availability, low quality of protein, low nutrient density, and high bulk. The full-term Hispanic infant population of low socioeconomic class in urban areas of Santiago was selected to participate in a field trial to assess the effect of the iron-fortified rice flour on iron nutrition status.

Vehicles: Extruded rice flour obtained from a local supplier.

Fortificant: Bovine haemoglobin concentrate (BHC). BHC is a fine, dark red powder obtained by centrifugation and further dehydration of the corpuscular fraction of blood of slaughtered animals. L-ascorbic acid (20 mg/100 g of powder) was added as antioxidant in relation to the fat content. To balance the Ca/P ratio, $CaCO_3$ (500 mg/100 g of rice) was added as well.

Fortification level: The level of fortification used was 5% BHC (iron content 280 mg/100 g of powder), which means 14 mg of elemental iron per 100 g dry product. Assuming an average daily intake of dry cereal of 40 g/infant and an absorption rate of 14.2%, it provided 0.8 mg of absorbed iron/infant per day. Geometric mean absorption of the rice-BHC iron was 14.2%, which is slightly over one-third of the optimal absorption of elemental iron.

Technology: Process and equipment: The rice flour was extruded in a 6" Anderson Expansion Extruder-Cooker (Anderson Ibec, Strongsville, Ohio, USA). After processing, the extruded flour was dried to 10% moisture content and ground over a 60-mesh sieve. A premix of BHC, L-ascorbic acid, and $CaCO_3$ was then dry mixed with the extruded rice flour.

Flow chart: See this chapter under "Wheat Processing."

Status: Field trial. A group of 92 breast-fed infants from 4 to 12 months of age received the fortified cereal. A control group of 96 infants received regular solid foods (cooked vegetables and meat). At the end of the trial, a subsample of infants in both groups was supplemented with 45 mg Fe for 90 days. At 12 months, iron deficiency anemia was present in 17% of controls, in 10% of fortified infants as a whole, but only in 6% of the infants who consumed more than 30 g of rice/day, demonstrating that the consumption of haemoglobin-fortified rice is effective in reducing the incidence of IDA in breast-fed infants.

Project/program evaluation: The use of a haem-iron fortified cereal as a weaning food seems feasible and advantageous, supplying an appropriate amount of absorbable iron, an adequate energy density, and a protein that could complement milk protein.

SALT

Countries: India and Thailand.

Organizations and groups involved: In India: National Institute of Nutrition, Hyderabad; Food and Nutrition Board, Ministry of Agriculture; Ministry of Food and Civil Supplies, Madras; All India Institute of Hygiene and Public health, Calcutta; Institute of Child Health, Madras; All India Institute of Medical Sciences, New Delhi; Haryana Agricultural University, Hisar; Machine Build Industries Pvt. Ltd., Madras, India. In Thailand: Ministry of Health, Bangkok; and Mahidol University, Bangkok.

Target group: Iron deficiency anemia (IDA) is an important public health problem in India. It has been estimated that up to 60% of preschool children, 30% of women of child-bearing age, and 50% of pregnant women suffer from anemia. Iron deficiency anemia is particularly prevalent in the Northeast Region of Thailand where an estimated 40% of the population suffers from IDA, due, among other factors, to the relative isolation of villages, extreme poverty, and poor living conditions.

Vehicle: Common salt is considered to be a suitable vehicle for salt fortification, satisfying all the criteria of an ideal vehicle in India and Thailand:

- Salt is consumed by all segments of the population,
- There is no relation between salt consumption and socioeconomic status of the population, and
- Daily salt consumption has a narrow range of 12–20 g, with an average intake of 15 g/day.

Fortificants: In identifying the iron source for fortifying salt, the following criteria were considered:

- Iron sources must be stable when mixed with salt,
- It must not develop colour when mixed with salt,
- It must not impart colour or taste to the food to which the salt is added,
- It must be stable under the prevailing conditions of storage and transportation of salt, and
- Bioavailability of the iron source must be satisfactory, particularly when the iron-fortified salt is added to food during cooking.

Although ferrous sulphate is the most suitable iron salt from the point of view of bioavailability and cost, it is unstable and develops colour readily when added to NaCl. Ferric phosphate and other insoluble iron compounds are stable and do not develop colour, but the iron absorption rate is unacceptably low, particularly when ingested with food.

Two approaches were investigated: the use of stabilizers to prevent discolouring and absorption promoters to improve bioavailability. The use of sodium hexametaphosphate and

sodium acid sulphateas stabilizers was proposed (Diamond et al. 1974). Absorption promoters have been found to have better keeping quality without deterioration of iron availability. With sodium acid sulphate ($NaHSO_4$), the iron absorption from ferric phosphate ($FePO_4$) significantly increased to nearly double the rate and reached 80% of the value obtained with ferrous sulphate ($FeSO_4$). The formula was improved (Rao et al. 1978) to avoid occasional yellow discoloration and to reduce the cost. Instead of the more expensive $FePO_4$, a mixture of $FeSO_4$ and sodium orthophosphoric acid (NaH_2PO_4) can be used.

Studies in Thailand concentrated on the use of stabilizers. A formula based on Na-hexamethaphosphate and $NaHSO_4$ was tested (Suwanik et al. 1980). Iron absorption and stability from a meal containing this fortified salt is reported satisfactory. This is contradictory to the findings of Rao et al. (1975) who reported deterioration of iron availability on storage due to formation of insoluble ferric phosphate.

Fortification level: The fortificant as produced in India from $NaHSO_4$ (5,000 ppm), $FeSO_4$ (3,200 ppm), and NaH_2PO_4 (2,200 ppm) provides one gram of elemental iron per kg of fortified salt (1,000 ppm). Absorption of iron in the cereal-based diet in India is impaired due to the high phytate content of these diets. Assuming an absorption rate of 5% and an average intake of 15 g of salt/day per person, it provides 0.75 mg of additional absorbable iron/day. This is just over one-third of the average daily iron requirement in India.

The fortificant made in Thailand from $FeSO_4$ (5,000 ppm), Na-hexametaphosphate (4,000 ppm), and $NaHSO_4$ (3,000 ppm) give a fortified product containing one gram of elemental iron per kg of fortified salt (1,000 ppm). Assuming an absorption rate of 10% of the total intake of iron in the Thai diet and an average intake of 10 g of salt/day per person, it provides about one mg of additional absorbable iron/day.

The processing required for different grades of salt is summarized in the next column:

Category	*Type*	*Processing required*
a.	Unrefined	Grinding and washing Centrifuging and drying Fortification and packaging
b.	Semirefined	Centrifuging and drying Fortification and packaging
c.	Refined	Fortification and packaging

Technology: Process and equipment: For salt that needs to be refined the following steps are involved:

Grinding and washing: Raw salt is fed into a hopper and delivered at a uniform rate through a roller feeder and bucket elevator to a hydromill into which brine is also introduced. Here, the salt is ground and discharged as slurry into a slurry receiving tank where fresh brine is once again introduced. The gypsum and fine insolubles are separated by floatation with froth formed in the hydromill. The salt slurry is then pumped through a slurry pump to a thickener where the salt concentration is increased before it is fed into a continuous centrifuge. The wash brine is returned to a brine tank from where it is repumped to the thickener. The wash liquor carrying impurities is sent to a sludge pit where the insolubles settle. The clear brine is recirculated through the pump to the slurry receiving tank.

Centrifuging and drying: The brine is given a fresh water wash and its moisture content should be reduced, in the centrifuge, to about 3%. The centrifuged salt is passed through a fluid bed drier where it is dried to a moisture content of less than 0.15% and then cooled.

Fortification and packaging: After refining and drying, the dried salt is transferred through a bucket elevator to a vibrating screen and sieved. The undersized particles are fed to a continuous mixer where the salt is dry blended with a premix of salt and $NaHSO_4$, $FeSO_4$, and NaH_2PO_4. The fortified salt is packed in 50 kg bags or retail packs of 0.5 or 1 kg. The blending technique is critical as improper mixing could result in ununiform fortification and discoloration of the salt either immediately or within a few days of mixing. For salt delivered to the iodization plant as a semirefined grade, the grinding and washing step is not necessary. When refined salt is used, only the fortification and packaging step is required. In Thailand, instead of dry blending, spray-mixing was applied to fortify salt with iron because this technique gives a consistent and uniform iron concentration.

Flow chart: See Chapter 4 (Fig. 4-1c).

Status: Based on a community trial among children aged 5–15 years (Nadiger et al. 1980) and field trials among the rural population (Nadiger et al. 1980; Working Group Report 1982), fortified salt made a significant improvement in haemoglobin levels and in reducing the prevalence of anemia. The impact was the highest in a region where the incidence was highest. A further study among female college students confirmed these findings (Jain et al. 1987). Steps have been taken to implement this program on a national scale.

The Tamil Nadu project is expected to cover two districts in the state and the Midday-Meal Programs for school children (covering roughly 2.5 million people). UNICEF has carried out Knowledge, Attitudes, and Practices (KAP) studies in these areas and has prepared a detailed publicity campaign for iron-fortified salt (Mannar 1991).

Consumer acceptability trials have been carried out with salt fortified with $FePO_4$-$NaHSO_4$ in India. This fortified salt was

found to be generally acceptable in both the community trials in schools and the field trials in four regions in India. Field trials are reported to be under way in Thailand, but results of this study are not available (Suwanik 1980).

Product: Salt fortified with $FePO_4$ and $NaHSO_4$ in 1:2 molar proportions was found to be stable over 8 months, and iron absorption did not deteriorate on storage. Crude salt with a high content of magnesium chloride ($MgCl_2$) occasionally gave a yellow discoloration, which gradually disappeared within 10 days on exposure to the atmosphere. Salt fortified with a mixture of $FeSO_4$, (NaH_2PO_4) and $NaHSO_4$ was found equally good with respect to bioavailability and stability, while occasional discoloration did not occur. When used in cooking, taste or colour of the product was not altered.

Salt fortified with a mixture of $FeSO_4$, Na-hexametaphosphate, and $NaHSO_4$ gave good bioavailability in tests in Thailand. Taste or colour were not altered and no significant reduction in iron levels after storage of up to 15 months was observed. No change in taste and palatability was noted when used in more than 50 common Thai recipes, which involved boiling, roasting, frying, steaming, grilling, salting, sundrying, or fermentation.

Quality aspects: The purity of salt used for iron fortification is a critical factor to ensure the stability and bioavailability of the iron compound. Presence of moisture in the salt hastens hydrolysis of the ferrous salts and imparts a brown colour to the salt. The presence of a high level of magnesium (Mg) in the salt increases its tendency to absorb moisture and aggravates the problem. Salt used for iron fortification will require a minimum purity of 99% (dry base), a maximum moisture content of 0.5%, and a maximum Mg level of 0.05%. The salt should be fine and be of uniform size (0.5–1 mm).

Effective implementation of a program for producing and distributing iron-fortified salt requires regular monitoring, particularly at the retail and household levels. A simple, inexpensive field kit has been developed for this purpose (Ranganathan and Rao 1992).

Marketing/distribution channels: A well-established distribution system exists in India. The production of iron-fortified salt on a commercial scale has recently been approved by the Government of India. Specifications for iron-fortified salt have been incorporated as part of the regulations governing the Prevention of Food Adulteration Act. Private companies in Madras and Hyderabad have begun marketing iron-fortified salt in limited quantities. In the states of Tamil Nadu and Rajasthan, large commercial-scale fortification plants are being established by government-owned companies. Of the estimated annual production of 7 million tons of salt, about 4.5 million tons are available for human consumption, most of which is produced in about 120 manufacturing centres.

Cost effectiveness: On the basis of prevailing prices in India (as of 1991), the cost of machinery has been estimated at US$110,000 for a unit producing one ton/hour. The cost of processing fortified salt including the cost of chemicals and packaging (at 1985 levels) are estimated at US$25/ton and US$16/ton when using FePO4 and $FeSO_4$-NaH_2PO_4, respectively. Iron fortification adds about 50–80% to the cost of salt and costs US$0.20/person per year.

Project/program evaluation: The National Institute of Nutrition, India, is evaluating the impact of the fortified salt in two districts in Tamil Nadu state. Baseline surveys have been completed. (Mannar 1991). The results of the impact evaluation are discussed under "Double Fortified Salt."

Observations: Although this approach would help to reduce the incidence of mild and moderate grades of anemia in the community, it is unlikely to meet the iron needs of pregnant women who may have the most severe forms of anemia with associated highest risks.

Even though technology for iron fortification of salt has been developed and field trials confirming the effectiveness of the formulation were completed in the 1970s, the program did not find large-scale application, partly because it was overtaken by a major thrust in several developing countries, including India, to iodate salt to control IDD. In some countries like Sri Lanka, cooking salt is steeped in water and only the saturated brine is used for cooking. In such cases, fortification of salt with iron may not be feasible.

There was no evidence of the presence of inhibiting factors such as phytates and phosphates in the Thai diet. The absorption of iron was enhanced by the presence of protein in the form of small fish and by the ingestion of papaya, which contains ascorbic acid.

Future requirements/developments: Given that the infrastructure for salt iodation is now in place in several developing countries, this presents an opportunity to introduce iron along with iodine in the salt.

FISH SAUCE (NAMPLA)

Country: Thailand.

Organizations and groups involved: The Faculty of Tropical Medicine, Mahidol University, Bangkok; The Swedish Medical Research Council; and WHO.

Target group: The prevalence of anemia in Thailand is estimated to be 30–50%, due to a high incidence of hookworm infection and a low intake of iron from animal foods. Anemia, due to iron deficiency, is probably most severe in the north-eastern part of Thailand (Tuntawiroon et al. 1980).

Vehicle: In Thailand, the use of fish sauce as a condiment, flavour, or salt substitute is widespread. Fish sauce is an important salt substitute. Whereas solid salt is usually not in

the market in the local village shops, fish sauce always is. It is used in most kinds of foods and is added during cooking.

Fish sauce has been produced in some 130 factories (Garby and Areekul 1974). Of these factories, some 10–15 of the largest companies produce roughly 80% of the total amount of fish sauce produced. The consumption of fish sauce has increased from 20–30 million litres in 1962 to 40–80 million litres in 1967. The main reason for the increasing production is the increasing consumption in the rural areas. The improved transport facilities have opened the rural areas for centrally processed products. The average consumption of fish sauce is 10–15 ml/head per day (estimates for the average consumption by the military forces is 25 ml/head per day).

In 1969, Garby suggested fish sauce as a suitable vehicle for iron fortification to the WHO Nutritional Division for these reasons:

- Its low price;
- Wide-spread consumption;
- Fairly constant consumption level of 10-15 ml/person/day; and
- Overall availability in the market.

Overconsumption of the product is highly unlikely as its salt content limits the amount that can be consumed without negative organoleptic effects.

Fortificants: The following iron fortificants were tested in the laboratory:

1. Iron(III) Sodium Ethylenediaminetetra-Acetate (NaFeEDTA).
2. Iron(III) Choline Hydroxide Citrate.
3. Iron(II) Glycine Sulphate.
4. Iron(II) Digluconate.
5. Iron(II) Succinate.
6. Iron(II) Sulphate.

The fortification concentration was 0.5 and 1.0 mg elemental iron/ml fish sauce.

Only the first iron compound (NaFeEDTA) proved suitable as a fortificant. Fish sauce is a clear brown liquid that masks well any discoloration caused by the addition of the iron fortificant. Only the NaFeEDTA, however, did not change the visual appearance, whereas the other fortificants (2 through 6) were rapidly precipitated (from a few minutes to some hours).

The status of $NaFe^{(III)}EDTA$ as a recognized food additive is not yet clear. JECFA (1993) has reached the conclusion that $NaFe^{(III)}EDTA$ is safe when used in supervised food fortification programs in iron-deficient populations and has given provisional approval for its use. NaFeEDTA did not alter the pH of the fish sauce. Further organoleptic tests showed no significant effect of the NaFeEDTA fortified fish sauce on the taste of the meals prepared with the fortified fish sauce (Garby and Areekul 1974). Absorption tests showed that the iron present in the food with the fortified fish sauce is well absorbed.

Status: After laboratory tests were done to identify a suitable iron compound, a one-year field trial in two villages situated in the Central Plain of Thailand was conducted. This area is considered to be representative of the economic and social structure of the majority of Thai provinces where 80–90% of the population are rice-growing farmers. The area, however, is not as severely affected by iron deficiency anaemia as the north-eastern provinces. The fish sauce, used in the field trial was fortified with 6.56 mg NaFeEDTA. The results showed that because of the fish sauce fortification program it is possible to increase iron intake by 10–20 mg of Fe/person per day. The trial duration (one year) is too short to provide optimal beneficial results but the results imply that a continuous consumption of the fortified fish sauce should be expected to give good anemia-reducing results.

Fortification level: One mg elemental Fe/ml sauce, which correspondents with 6.56 mg NaFeEDTA/ml sauce extraction of marine fish. The salt content of the product is 30 g/l and the iron content is 10 mg/l. The variance in fish sauce qualities is dependent of the degree of extraction, the cheaper qualities being dilutions of the high-extraction-rate qualities. Problems with colour, taste, and odour, caused by the iron fortificant, are minimized by choosing this highly flavoured product as the vehicle.

Technology, process, and equipment: A small factory in Bangkok was asked to fortify the sauce for the pilot project. The NaFeEDTA was added to the fish sauce just before bottling. The bottles were transported to the villages once in every 2 months. The village head man was responsible for storage and distribution of the fish sauce to the villagers when needed.

Full-scale production: No large-scale industrial fortification program has been reported in the international literature (INACG 1993).

Product: The product is a clear brown liquid with a pH of about 5.5, produced by salt extraction of marine fish. The salt content of the product is 30 g/l and the iron content is 10 mg/l. The variance in fish sauce qualities is dependent of the degree of extraction, the cheaper qualities being dilutions of the high-extraction-rate qualities. Problems with colour, taste, and odour, caused by the iron fortificant, are minimized by choosing this highly flavoured product as the vehicle.

Cost effectiveness: The costs of the fish sauce fortification as suggested by the field trial will increase the costs of the product by 10–20% or by about 0.3–1.0% of the average monthly cash income of a Thai farmer. A less pure grade (>97%), however, as is used in the agricultural industry as a fortificant, is commercially available at less than half the costs of the pharmaceutical $NaFe^{(III)}EDTA$ (Ballot et al. 1989). The

costs of food fortification with NaFe(III)EDTA as a food additive may also be reduced with the alternative fortification mixture Na_2EDTA plus $FeSO_4$ in a molar ration of 0.5:1.0 in diets (INACG 1993).

Project/program evaluation: The active role of the fish sauce processing industry is limited to one producer in Bangkok who provides the fortified product. It is important to include the fish sauce processing industry as a whole in a very early stage of the program to maximize their cooperation in pilot tests and full-scale production. Viteri et al. (1981) and Cook and Reusser (1983) report a large-scale fish sauce fortification program being conducted in Thailand.

Future requirements/developments: The JECFA (1993) stated that NaFeEDTA is safe when used in supervised food fortification programs in iron-deficient populations and has given provisional approval for its use. A cheaper yet very promising alternative is the use of Na_2EDTA and $FeSO_4$ in the molar ratio of EDTA to iron between 1.0 and 0.25 in meals of low iron availability. In a large-scale/full-scale fortification program both these iron sources may be tested for efficacy.

CURRY POWDER (MASALA)

Project title: Fortification of curry powder with NaFe(III)EDTA.

Country: South Africa.

Parties involved/cooperation: The Medical Research Council (MRC), the University of Witwatersrand, the University of Natal, and the Indian population of South Africa.

Target group: The Indian population of Durban shows a high prevalence of nutritional iron deficiency. Mayet (1972, 1976) found evidence of iron deficiency in 20% of the male and in 33% of the female population. In a later study, McPhail et al. (1994) reported IDA in 14% of the females in the reproductive age in the same Indian population. A further 26% was shown to have depleted iron stores and another 8% had iron-deficient erythropoiesis (IDE). In a recent study, Ballot et al. (1989a) found evidence of iron deficiency in 30% of the male and 60% of the female Indian population in Natal. Of the females, 24% had IDA, 13% IDE, and 16% had depleted stores. This is ascribed to a high pregnancy rate and a diet in which the bioavailability of the iron is low (Mayet 1972; McPhail 1981). The Indian population of Natal was, therefore, selected for a pilot program to establish the feasibility of a fortification program using curry powder.

Vehicle: The choice of an appropriate vehicle was complicated by the fact that the black South African population shows a high prevalence of iron overload, due to the traditional method of beer brewing in cast-iron pots. This excludes the choice of a staple food like flour as the vehicle for the iron fortification (MRC 1978). Masala was especially suited to serve the goal of the project because it has the following characteristics:

- Regular consumption,
- Relatively constant amounts (average of 5.5 g/d) consumed by a high percentage of the target population,
- Not consumed by the nontarget population,
- Good masking qualities (dark colour and strong aroma), and
- A slight iron absorption-enhancing effect of the vehicle (Lamparelli et al. 1987).

Fortificants: FeEDTA is the only known nonhaem iron fortification source that resists the inhibitory effect of phytic acid, a component of cereals and grain legumes, which is the main compound of the target group's diet. Studies have shown that the iron absorption from NaFe(III)EDTA fortified foods is significantly better than from other fortified foods. Mean bioavailability of the fortificant was about 10%. Lamparelli (1987) showed that the mean iron absorption from NaFe(III)EDTA-fortified masala was almost twice that of ferrous sulphate, when each was taken together with a traditional vegetable meal. An increase in the iron absorption of approximately 7 mg/day was established. In the study, an absorption increase of 12 µmol/d in iron-depleted women was demonstrated. No adverse effects in individuals with normal iron status at the beginning of the experiments was observed.

Fortification level: 10 mg NaFe(III)EDTA/g curry powder, which equals 1.4 mg Fe/g curry powder.

Product: Commercial masala was purchased from a local supplier. Experimental batches of fortified masala were prepared by the investigators in a separate location. The local supplier packaged the experimental batches in the regular packaging material. The level of fortification was 10 mg NaFe(III)EDTA/ g curry powder, which equals 1.4 mg iron/g curry powder. Consumer acceptability was assessed using a questionnaire. Acceptability in terms of taste and appearance was high. The NaFe(III)EDTA showed no tendency to segregate, the curry powder being slightly sticky. Stability after several months of storage was good.

Technology: Process and equipment: No commercial production of fortified masala has yet been reported. Production is still at the laboratory phase.

Status: Lamparelli (1987) describes an experiment that was designed to study the acceptability of curry powder as an iron fortification vehicle and the suitability of NaFe(III)EDTA as the fortificant.

Ballot et al. (1989b) describes a field study, which assesses the effect of fortification of curry powder with NaFe(III)EDTA on the iron status of the target population. No further investigations and/or trials with NaFe(III)EDTA fortified curry powder have been reported. Investigations are now concentrated on the

issue of the optimal molar ratio of Na_2EDTA to iron in meals of low bioavailability (McPhail et al. 1994).

Cost effectiveness: The pharmaceutical grade $NaFe^{(III)}EDTA$ used in the study raised the price of the fortified masala by 15%. A less pure grade (>97%), however, as is used in the agricultural industry as a fortificant, is commercially available at less than half the cost of the pharmaceutical $NaFe^{(III)}EDTA$ (Ballot et al. 1989).

The costs of food fortification with $NaFe^{(III)}EDTA$ as a food additive may be reduced with the alternative fortification mixture Na_2EDTA plus FeSO4 in a molar ration of 0.5:1.0 in diets (INACG 1993).

Project/program evaluation: The status of $NaFe^{(III)}EDTA$ as a recognized food additive is not yet solved. JECFA (1993) has reached the conclusion that $NaFe^{(III)}EDTA$ is safe when used in supervised food fortification programs in iron-deficient populations and has given provisional approval for its use.

Although the results of the field trials are very promising, introduction of a full-scale operational food fortification program is not possible. A very promising alternative is the use of Na_2EDTA and $FeSO_4$ in the molar ratio of EDTA to iron between 1.0 and 0.25 in meals of low iron availability.

Future requirements/developments: Thus far, an active role of the masala producers, with regard to advise on the feasibility of the process in the existing processing facilities, packaging, price setting, and the marketability of the product is not reported. When active cooperation of the industry is guaranteed, steps to develop a monitoring unit and a program evaluation procedure can be taken.

OTHER FOOD VEHICLES

Barley-sprout flour

Abstract: In an attempt to increase the iron content of barley flour, seeds were soaked in distilled water for 6 hours and grown hydroponically under controlled conditions in the dark for 132 hours. They were sprayed automatically every 4 hours for 15 minutes with either distilled water or distilled water to which iron as ferrous sulfate had been added at 5, 7, and 10 ppm iron concentration. The sprouts were frozen, freezedried, ground into flour, and analyzed for iron. Iron bioavailability was evaluated by the efficiency of converting dietary iron to haemoglobin. Increasing the concentration in the iron in the spray water resulted in marked increases in sprout iron levels, but solutions of 7 ppm and above inhibited seed germination. Iron from the sprouted barley flour was significantly more available than that from the ungerminated barley seed flour (Alexander and Cudjoe 1989).

Cheese

Abstract: Dairy products contribute high-quality protein, calcium, and other nutrients to the human diet but are low in iron. Zhang and Mohoney (1991) fortified cheddar cheese with Fe-casein, Fe-whey protein, or $FeCl_3$. Iron concentrations in the fortified cheese were 40 mg/kg, whereas the iron content of the unfortified control cheese was 1–2 mg/kg. The quality was determined by thiobarbituric acid assay and taste panel evaluation. After 3 months of storage no difference in oxidized off-flavour or cheese flavour, texture, and quality between the fortified and unfortified cheese was detected.

Results indicate that it is possible to produce good-quality, iron-fortified process cheddar cheese. Similar results were obtained by Wong and LaCroix (1979) who fortified cottage cheese with ferric ammonium citrate. This study demonstrated that milk protein does not affect iron absorption and that the fortified cheese is effective in restoring low haemoglobin. Jackson and Lee (1992) fortified Havarti-style cheese with microencapsulated iron. The cheese was fortified with stearine coated microcapsules containing iron as $FeSO_4$, $FeSO_4$ + ascorbic acid, or $FeCL_3$ with up to 141 mg iron/kg of cheese. Sensory evaluation indicated that cheese with encapsulated $FeSO_4$ + ascorbic acid was indistinguishable from cheese without iron.

Other iron-fortified cheese types had high initial concentrations of malonaldehyde and undesirable oxidized flavours. Unencapsulated iron salts are not suitable as fortificants due to their reactivity. The rapid and simple stearine microencapsulation method allows fortification of dairy products and other high fat and high moisture foods with iron (Jackson and Lee 1992).

Coffee

Abstract: Coffee grounds were fortified with ferrous fumarate and the resulting perked coffee was fed to rats (Johnson and Evans 1977). Fe-fumarate mixes well with coffee grounds and is undetectable after mixing. It did not sift out after 3 months of storage. Taste panels could not tell the difference in organoleptic properties of fortified and unfortified coffee. Bioavailability of the iron was assessed with the extrinsic label technique. For black coffee, coffee with sugar, coffee with nondairy creamer, coffee with milk, and coffee with sugar and nondairy creamer, bioavailability of the iron averaged $39 \pm 12.1\%$. There was no significant difference in iron absorption from the coffees.

Assuming that iron absorption in rats and humans is similar, coffee could supply a substantial amount of the daily iron requirement. At a level of 5 ppm in brewed coffee, four cups (200 ml each) would supply 4 mg iron in the diet. Layrisse (1976) has reported addition of iron-fortified sugar to coffee without adverse effects on its organoleptic properties.

It is suggested that iron fortification of coffee might be a feasible method of increasing iron intakes for many people. Morck et al. (1983), however, concluded that when the coffee was ingested directly with or within an hour after a meal, iron absorption was reduced dramatically. No decrease in iron absorption occurred when coffee was consumed within an hour before a meal (Layrisse et al. 1976; Johnson and Evans 1977; Morck et al. 1983).

Eggs

Abstract: Eggs are an important source of dietary protein and potentially could add appreciably to the dietary iron absorption. The poor absorption from egg yolk (10% of that from ferrous iron salt), however, detracts from their value in this respect. Another disadvantage of eggs in relation to iron metabolism is their interference with iron absorption from other sources. Eggs do not, however, appear to interfere with the absorption of iron from haemoglobin, which emphasizes the importance of haem iron in iron nutrition. The addition of orange juice to the meal shows a highly significant positive effect on iron absorption (Callender et al. 1970).

Grain amaranth cereal

Abstract: Iron bioavailability in Nigerian grain amaranth cereal fortified by two iron compounds, sodium ethylenediaminetetraacetate (NaFeEDTA) and ferrous fumarate ($FeC_4H_2O_4$), was compared with that in cereal fortified with ferrous sulphate. Grain amaranth is important because of its potential as a cereal for young children in Nigeria and other Third World countries. Although haemoglobin gain in all three groups fed fortified cereal was significantly higher than that in the group given no added iron, haemoglobin gain was highest in animals fed amaranth cereal with ferrous fumarate. High relative biological values and expected body weight gain indicated optimum iron absorption from the amaranth cereal. The study indicates that ferrous fumarate is the iron fortifier of choice for grain amaranth cereal (Whittacker and Ologunde 1990).

Maize meal

Maize can be readily fortified with iron without any technical problems. Dry-milled maize meal fortified with reduced iron (88 mg/kg) was stable after 56 days of accelerated storage. To date, maize meal has not been considered as a food vehicle in developing countries because a considerable amount of the maize consumed is processed at the home. Given the increasing numbers of urban migrants dependent on processed food, however, it may be appropriate to consider maize meal as a primary vehicle for iron in countries where maize is a staple food (Nestel 1993).

Potato starch

Abstract: In spite of the fact that starch present in the diet lowers the assimilation ability of iron added to food, for technical reasons bread and flour products are most frequently enriched with iron. This provides the possibility to enrich these products with a supplement of potato starch after its saturation with ferric salts. Starch saturated with ferric chloride or ferric citrate solutions and containing 7–80 mg Fe/100 g of dry matter was examined.

The increase in iron content was higher in the case of chloride than of citrate and did not depend on the previous rinsing of starch with water or 1/10 M hydrochloric acid. Simultaneously, with the increase of iron content, the viscosity of 0.25% starch pastes decreased when rinsed with water, whereas it increased when rinsed with hydrochloric acid. Starch containing 60–80 mg Fe/100 g of dry matter was characterized by a lowered susceptibility to degradation by alpha-amylase an glucoamylase (Leszczynski 1985).

Other single iron-fortified foods

The use of *wheat flour noodles* for iron and other micronutrient fortification is currently under consideration in Indonesia. The main constraint is the lack of expertise in this technical area.

Kool-aid is an example of a beverage fortified with iron and is under development in Egypt. Because of its dark colour, this beverage could be a suitable vehicle for iron fortification (Nestel 1993).

SINGLE FORTIFICATION WITH VITAMIN A

FATS AND OILS

Fats and oils are used directly or as food ingredients. Whereas oils refer to liquid products like oils from canola, corn, cottenseed, coconut, olive, palm, peanut, safflower, soybean, and sunflower, fats are solid products such as butter, lard, shortenings, margarine, ghee, tallow, and vanaspati. Fats and oils are suitable as vehicles for vitamin A because:

- Vitamin A and provitamin A compounds are highly fat soluble and, when added to fats or oils, distribute easily and uniformly;
- Vitamin A is more stable in fats and oils than in other foods as they are protected from air contact, this delays their oxidation and prolongs their stability;
- Dietary fat facilitates absorption and utilization of vitamin A in the body, therefore, its fortification with vitamin A is one of the most appropriate means of supplying this vitamin to a deficient population; and
- Fats and oils are used directly or are basic ingredients of most diets and are, thus, consumed by almost everyone. High coverage of the population with fortified fats and oils can, thus, be achieved.

Countries: A large number of developed and developing countries. Commercial production of vitamin A fortified margarine started as early as 1927.

Organizations and groups involved: Fats and oils processing industry, MOH, University of Liverpool, Pennsylvania State University, University of Sao Paulo, Hoffmann-La Roche, Unilever, University of British Columbia, Procter & Gamble.

Vehicles:

Edible oils: Vegetable oils from maize, olive, peanut, soybean etc. Fortification of refined soybean oil is currently under trial in Brazil (Favaro et al. 1991, 1992). In India, red palm oil is added to peanut oil and distributed as a concentrate providing vitamin A corresponding to 100% of RDA of an adult male.

Lard, shortening, ghee, vanaspati: Mixture of fats/oils.

Margarine: Ripened skim milk and mixture of fats/oils.

Product:

Margarine is an economical, nutritious, and palatable substitute for butter. It resembles butter in appearance, form, and composition using a vegetable-based fat and oil mix. Shelf-stable margarine that does not require refrigeration is now available in many countries.

Vanaspati is a hydrogenated vegetable fat used as a butter substitute in India.

Fortificants: Vitamin A acetate or palmitate ester (vitamin D and E optional). The fortificant used for soybean oil in Brazil is retinol palmitate + antioxidants.

Fortification level:

Edible oil: Vitamin A was added at a rate of 200 IU/g of oil, based on a daily consumption of 15–30 g of oil per person in Southern Brazil. Fortification of edible oils at a level of 20 IU/g was made compulsory in Pakistan for over 20 years now. But it is not enforced or monitored. Actual levels, therefore, vary from 0 to 20 IU/g oil.

Vanaspati (hydrogenated fat): Fortification with vitamin A (25,000 IU/kg) was made compulsory in 1953 in India. The addition of vitamin D is optional, but most manufacturers voluntarily add vitamin D.

Margarine: On average, about 30,000 IU of vitamin A and 3,000 IU of vitamin D are added per kg of margarine. In Table 7-9, the fortification level in a number of countries is shown. Recently, fortification of shelf-stable margarine in the Philippines has been shown to be highly effective in improving the vitamin A status of preschool Filipino children (Solon et.al. 1994).

Technology: Process and equipment

Edible vegetable oils: Used as salad oils or for light cooking in household, vegetable oils can be fortified with vitamin A. After clarification, a vitamin A ester in the form of an oily liquid concentration is added and carefully agitated for uniformity. Edible antioxidants may also be added to protect both the vegetable oil and the vitamin A ester from oxidation.

Lard, shortening, ghee, vanaspati and other hydrogenated fats can likewise be fortified technologically in a similar way.

Margarine: The production of margarine is done in a batch or continuous process. The oily vitamins are mixed thoroughly in warm oil (ratio 1:5) to produce a uniform solution that is added to the fat blend before the emulsifying process (see Fig. 7-2).

Status and results of field trials: Full-scale production in many countries. Fortification of soybean oil is currently under trial in Brazil with promising results.

Table 7-9. Vitamins A and D commonly added to margarine.

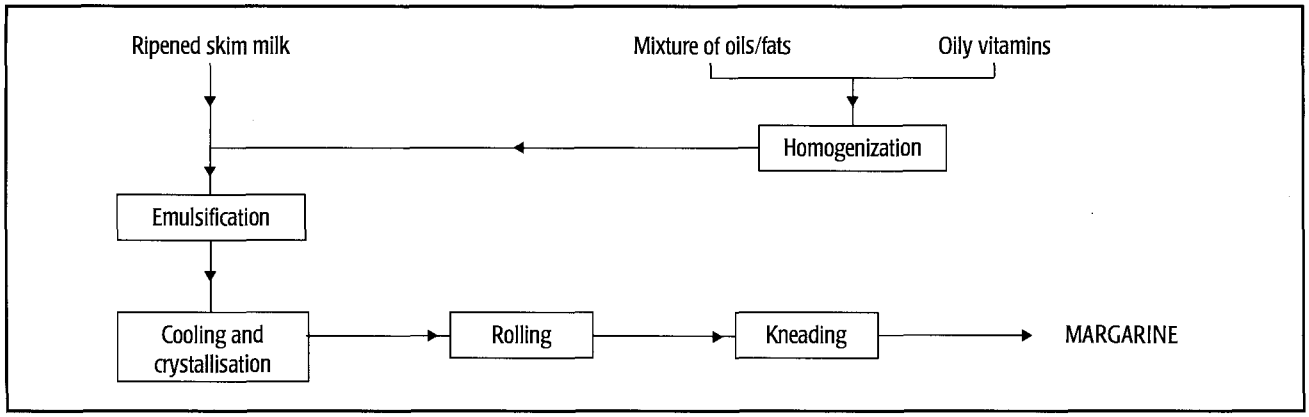
Country	Vitamin A (IU/kg)	Vitamin D (IU/kg)
Australia[a]	30,000	4,000
Austria[c]	20,000	3,000
Belgium[c]	16,000	3,000
Brazil[b]	15,000–50,000	500–2,000
Canada[c]	35,000	7,000
Chile[b]	30,000	3,000
Colombia[b]	30,000	0,120–300
Denmark[c]	24,000	500
Finland[c]	16,000	2,400
France[c]		
Germany[c]	20,000	1,000
Greece[a]	25,000	1,500
India (Vanaspati)[c]	25,000	–
Israel[c]	30,000	3,000–4,000
Italy[c]	prohibited	prohibited
Japan[a]	30,000–40,000	–
Mexico[b]	20,000	2,000
Netherlands[c]	20,000	3,000
Norway[c]	20,000	2,500
Philippines[a]	22,000	1,100
Poland[c]	30,000	3,000
Portugal[a]	20,000–35,000	875–1,000
South Africa[c]	20,000	1,000
Spain[c]	20,000	3,000
Sweden[c]	30,000	3,000
Switzerland[c]	30,000	2,700
Turkey[a]	20,000	1,000
UK[c]	27,000–33,000	2,800–3,500
USA[c]	30,000	2,100

[a] Bauernfeind and Arroyave (1986).
[b] Nestel (1993).
[c] Kubler (1973).

Quality assurance:

Margarine: Storage of vitamin A-fortified margarine for 6 months at 20–25°C results in minimal losses (O'Brien and Roberton n.d.; Morton 1970). Heating at 160°C, 180°C, and 200°C resulted in losses of max. 20%, 35%, and 50% (Morton 1970). An average of 10% vitamin A and D is more to compensate for distribution variations rather than heat degradation. Losses occurring would be due to oxidation of the oily vitamins, a process that would cause rancidity of the fats at the same time. ß-carotene (provitamin A) is added as a colorant but it is also a significant source of vitamin A. Biological assays demonstrate full availability of added vitamin A (Bauernfeind and Arroyave 1986).

Fig. 7-2. Flow chart of vitamin enriched margarine manufacturing.



Source: O'Brien and Roberton, n.d.

Edible vegetable oils: Fortified oil was tested for acceptability in basic recipes for mayonnaise, fried beans, fried potatoes, soup, cooked rice, wheat tortillas, and fried meat. Consumers were not able to detect the difference between products prepared with or without fortified oil. Frying tests with cottonseed oil showed that the quality of the oil was best preserved at 160–180°C, and 60–80% of the vitamin A content was retained after 30 minutes of frying (Paden et al. 1979).

Research has been done on specific aspects of the stability of vitamin A in oils. Vitamin A palmitate in soybean oil stored in sealed cans in the dark retained its activity after storage for up to 9 months. After 18 months, its vitamin activity was more than halved, down to about 40% of the original concentration. The vitamin A activity of oil stored in open cans began to deteriorate after 6 months of storage. Oil stored in the dark retained 33% of its vitamin A activity, whereas oil stored in the light had a negligible amount of vitamin A after 18 months.

With normal household cooking (boiling or pressure cooking) the vitamin A activity remained nearly unchanged, but repeated use of oil in frying gradually destroyed the vitamin A (Favaro et al. 1991, 1992; Desai et al. 1994; Dutra Oliviera et al. 1994; University of Dhaka 1994). Because of the stability of vitamin A in oil, vegetable oil is used as a carrier by vitamin A manufacturers. According to Hoffmann-La Roche "the stability of the vitamins present in a fat is usually the same as the general stability of the fat itself." As the shelf life of such products as cooking oils and margarine is about 6–12 months, vitamin A losses in fortified oils can be expected to be minimal for this length of time. This compares favourably with vitamin A stability in solid food ingredients.

Shortening: In products of low fat content (bread, biscuits, cake), which are baked under moderate conditions, vitamin A appears to survive the baking process to the extent of 80–100% (Rice et al. 1942; Paden et al. 1979). The stability of vitamin A added to fatty foods is shown in Table 7-10.

Marketing/distribution channels: Through open market channels.

Cost and cost effectiveness: Margarine is cheaper than butter with similar nutritional value. Soybean oil in Brazil costs less than other oils and fats.

Project/program evaluation: Fully accepted in several countries. In many countries, vegetable oil processing is often centralized and controlled by large companies and cooperatives, thus facilitating large-scale fortification with vitamin A. Commercial vegetable oils are often packaged and sealed in metal cans and thus protected from light in storage.

The importance of margarine in the Western world can be compared with that of vanaspati in India. The vanaspati industry is one of the largest processed-food industries in India today.

Vegetable oil consumption, in particular soybean oil, is increasing rapidly throughout Brazil, especially among the lower economic sectors.

Observations: In some countries water soluble vitamins may be added. In this case, the vitamins would be dissolved in pasteurized milk (ratio 1:20) and added to the aqueous phase before pumping into the emulsification chur.

SUGAR

Countries: Fortification of sugar with vitamin A has been successfully implemented in various countries in Central and South America: Chile, Costa Rica, El Salvador, Guatemala, Honduras, and Panama.

- Brazil (Araujo 1978): Bioavailability study;
- Chile (Toro 1975): Bioavailability, field study, organoleptic analysis;
- Guatemala (Arroyave 1987): Bioavailability, field study, organoleptic analysis;
- Panama (Navia 1983);

Table 7-10. Stability of vitamin A added to fatty foods.

Type of fat/oil	Period of storage at 20–25 °C (months)	Loss of vitamin A (%)
Margarine	3	10–12
	6	15–20
Lard	2	2–7
	4	10–15
	6	15–20
Cooking fat	2	0–5
	4	5–10
	6	20–25

Source: Morton (1970); Klaui et al. (1970).

The International Sugar Federation at its May 1995 meeting in Sao Paulo, Brazil, recommended sugar fortification with vitamin A to all member countries where vitamin A deficiency is prevalent:

Organizations and groups involved:

Ministries of Health, INCAP (regional operating, program development), National agencies/research institutes/universities, International Sugar Institute, and UNICEF.

Target group: Originally, the program in Guatemala was targeted at the whole population (fortification levels set according to the RDA for adults). As the primary goal of the program was an adequate intake of vitamin A by preschool children, the target group changed to the preschool children, as is reflected in the level of fortification (Molina 1991).

Vehicles: Sugar was chosen for the following reasons:

- Universal and fairly constant consumption by the whole population,
- No organoleptic interference of the fortificant with the vehicle,
- Long shelf life,
- Economical feasibility (no substantial raise in the price of the fortified product in comparison to the nonfortified product), and
- Central processing facilities.

In Chile, 80% of the sugar is produced in two plants. Refined sugar is consumed in fairly constant amounts by the whole population (Navia 1968; Arroyave 1987). In Guatemala, sugar was chosen as a vehicle because it is produced through a relatively centralized process and is consumed regularly by adults and children. It is also added to liquid and cereal mixtures prepared for younger children (UNICEF 1994). In 1974, the Guatemalan Congress enacted a law requiring fortification with vitamin A of all sugar produced for domestic market. Regulations followed in 1975. Epidemiological surveys following a 2-year sugar fortification showed a significant positive impact on the vitamin A status of preschool children.

Such results were reconfirmed when vitamin A deficiency rose to its former level after fortification efforts lagged. Since the mid 1980s, Nutrition Institute of Central America and Panama (INCAP), UNICEF, and other agencies have participated in a broad-based effort to ensure adequate vitamin A consumption through sugar fortification, supplementation, and nutrition education. Sugar fortification was revitalized during the 1987–88 harvest following a concerted effort by UNICEF, INCAP, the National Association of Sugar Producers of Guatemala, and the Ministry of Health. Impact studies during the past 5 years indicate that vitamin A deficiency levels among preschool children in Guatemala have significantly decreased.

Fortificants: Retinol palmitate 250-SD Hoffmann-La Roche (water dispersible).

Retinol acetate 325-L Hoffmann-La Roche (water dispersible).

Fortification level: Based on the RDA suggested by WHO and the estimated daily sugar intake of Guatemalan preschoolers (20 grams, or about 2 teaspoons), INCAP recommended that sugar be fortified at a concentration of 15 micrograms (50 IU) of retinol per gram of sugar or 300 micrograms per day.

Product: Stability of the retinol acetate 325-L under various conditions (low temperature, room temperature with varying humidity, and room temperature with high humidity) was good. The maximum decrease of the retinol acetate 325-L was 20% after 8 months of storage. Paden (1979) reports a 89–90% recovery of the vitamin A in coffee and Incaparina after cooking. Recovery during the preparation of cakes was retained at 76%.

Organoleptic tests showed no effect on the taste of products as cakes and powdered juices, but a slight "medicinal" off-taste when mixed with coffee. No organoleptic differences between the fortified and the nonfortified sugars was detected by the population involved in the field study.

Technology: Process and equipment: The proportion of retinol palmitate added is 110% of that needed to fulfill the law and to compensate for any potential subsequent losses of potency. The proportions and ingredients used have been modified slightly over time but, in 1994, a batch of concentrated premix consisted of: sugar (75%), vitamin A palmitate (22%), sunflower or other peroxide-free oil to promote adhesion of the vitamin A compound to the sugar crystals (2.1%), and an antioxidant like Ronoxan (0.9%). These are mixed in a drum mixer or other proven equipment. A number of vitamin A sources have been investigated:

- Premix of sugar (of the same particle size as the final product) and vitamin A acetate 325-L (Toro 1975),
- Premix of sugar (of the same particle size as the final product) and vitamin A palmitate 250-SD (Paden 1979), and
- Premix of sugar (of the same particle size as the final product) and retinyl palmitate beadlets 250 CWS (Molina 1991).

The premix is bagged first in opaque plastic bags and then placed in fibre sacks, sewn together at the top to prohibit the entrance of light, and delivered to the mills as required. The fibre sacks are marked for content and with caution against human consumption of the premix.

The fortification process involves blending the premix with the regular white table sugar. It is the responsibility of the production manager to ensure that premix is added to domestic sugar. The premix can be introduced in the centrifuge at the end of the washing cycle. The amount of premix to be added must correspond with the charge per centrifuge. The premix is added to sugar by designated sugar mill employees (after the sugar emerges from the centrifuge and before it is dried), via a "dosage" machine produced in Guatemala. The machine is designed to vibrate as it works to spread the premix uniformly throughout the sugar and thus ensure the predetermined concentration of vitamin A in sugar.

During each 8-hour shift, an operator oversees the addition of the premix by pouring it into the hopper of the dosage machine, which in turn integrates the premix into the sugar as it moves along a conveyor belt. A bell has been added to the original dosage machine; when the machine is running low on premix the bell sounds, alerting the employee of the need to add more premix (UNICEF 1994). The fortified sugar is then placed inside 100-pound fibrous poly-propylene sacks in which it is distributed. The sacks are tightly closed and each is marked by weight, date, the name of the mill, and with a notification that it contains fortified sugar.

The premix can also be introduced during the transportation of the sugar (either before or after drying). This process requires an adjustable precision fee mechanism, synchronized with the propulsion system rate of the belt.

Stability and results of field trials: Toro (1975) reports on the laboratory studies to verify the absorption of retinol acetate 325-L in normal human individuals and on the fortified sugar stability tests. Absorbability of retinol acetate 325-L was significantly higher when the dose was administered together with a meal compared to the administration of retinol acetate 325-L without a meal. Both experiments showed an increase of serum retinol levels, at 50% and 115% of the basal value, respectively.

The sole source of vitamin A for the newborn is mother's milk; therefore, an adequate supply of vitamin A in the milk of a lactating mother is imperative for the health and appropriate growth of her baby. Bioavailability of added vitamin A to sugar in pregnant and lactating mothers was investigated by Arroyave (1974). Results indicated that lactation depletes vitamin A stores of lactating mothers. This depletion was arrested by the consumption of the fortified sugar.

Field studies have been done in an isolated population of a very low socioeconomic level with a high prevalence of VAD. The field study included:

- A nutritional survey in the experimental villages,
- A clinical examination, and
- An assessment of serum levels of retinol and ß-carotene.

All the inhabitants of the experimental villages were provided with fortified sugar over a 3-month period (a blind study with sugar consumption ad libitum). After 3 months, serum levels of retinol and ß-carotene were analyzed on the same individuals as were analyzed in the baseline period. During the following 3 months, regular sugar was provided, and after 3 months, the same parameters were determined in the population.

A significant increase in blood retinol levels was observed after three months of receiving fortified sugar. Blood retinol levels decreased after interrupting of the fortified sugar provision.

Blood ß-carotene levels did not change during the study (carotene was exclusively ingested from vegetable sources in the ordinary meal). The incidence of clinical signs attributed to VAD did not change during the (short) experimental period.

Quality aspects: Homogenous distribution of the vitamin A in the final product is assured by the good manufacturing practice when preparing the premix. Rapid quantitative methods for determining vitamin A distribution in the sugar have been developed for the sugar manufacturers. These instructions are distributed to the manufacturers through easy-to-read publications (Molina 1991).

Cost effectiveness: At the concentration of 0.021 mg retinol or 69.5 IU vitamin A/g table sugar the costs of vitamin A fortification of sugar was US$ 0.03/person per year (WHO 1976). This relatively low cost was a major factor in the decision by the Central American sugar manufacturers to absorb the costs of the food fortification program.

Project/program evaluation: Full-scale national programs have been operational in Costa Rica, Guatemala, Honduras, and Panama. The achievements are outstanding in the history of public health. Economical and political constraints are now hindering the continuity of the programs. Recently, these programs have received renewed attention in several of these countries.

Fortification of refined table sugar with retinol is legislated in Costa Rica, Guatemala, Bolivia, Panama and Honduras. The blood retinol levels (in 1965–1967) were in Costa Rica 32.5%, in Guatemala 26.2% and in Honduras 32.5%. In El Salvador the percentage of serum retinol levels of <20 μg/dl were 50% in 1965–1967. In 1977–1980, the prevalence of serum retinol levels < 20 μg/dl were: Costa Rica, 1.6%; Guatemala, 9.2%; and Honduras, 9.2%. Panama has not continued the compulsory fortification of sugar (Arroyave 1987). By 1994, 63% of sugar for human consumption was fortified in Honduras.

Future requirements: Sugar is a pure carbohydrate and does not contain the co-factors needed for its metabolism. Sugar metabolism is dependent, therefore, on provision of the co-factors involved in carbohydrate metabolism, such as thiamine and niacin, provided by other foods in the diet. The total dietary composition is of essential importance when the decision for the fortification of sugar is taken. Monitoring of sugar consumption patterns is essential. An increase in sugar consumption can lead to dilution of the nutritional quality of the diet and dental carries. The national sugar fortification programs have, therefore, opted for the policy that does not promote sugar consumption (compare the promotion policy in the MSG programs). Any type of advertisement or incentive to increase sugar consumption, and any emphasis to increase the consumption of sugar between meals, has to be avoided. Even if dietary modifications result in a decreased sugar consumption, this can easily be compensated by increasing the fortification concentration.

MILK AND MILK POWDER

Countries: In the Protein Advisory Group (PAG) bulletin (WHO 1976), many countries are listed where vitamin A deficiency is a public health problem and where fortified milk powder is needed. Food aid in the form of fortified dry skim milk (DSM) comes from Australia, Canada, the Netherlands, and the US. In the US, fortification has become mandatory for low fat milks. India has introduced fortification of milk with vitamin A in all major urban dairies.

Organizations and groups involved: WHO, FAO, UNICEF, FAD, USDA, FNB–NRC, CFN–AM, HPB–CDNHW; Hoffmann-La Roche Inc., Phillips-Duphar (main suppliers).

Target group: The target groups are particularly children and women of child-bearing ages in developing countries, but WHO's recommendation is to have a universal fortification rather than only covering groups at risk of vitamin A deficiency.

Vehicles: Because vitamin A deficiency mostly affects young children, the United Nations PAG recommended that DSM distributed by UNICEF and WHO in their programs be fortified with vitamin A (and vitamin D). This started in the 1960s. Usually, vitamin D is also added. In 1989, the United Nations High Commissioner for Refugees (UNHCR) and WFP issued guidelines on the use of milk powder as a food aid or in feeding programs. Based on these, dried skimmed milk has to be fortified with vitamin A before it can be accepted for distribution.

The Food and Nutrition Board selected milk as the ideal vehicle for vitamin A because it provided 10 % of the American customers' food energy and would not create an imbalance of the essential nutrients. Pasteurized and UHT low fat milks are fortified with vitamin A.

Fortificants: Vitamin A naturally occurs as retinyl esters (retinyl palmitate) in milk. ß-carotenes are also present in milk but their vitamin A activity is lower. The levels decrease by defatting the raw milk. Retinyl palmitate is commonly used to increase vitamin A in (partially) skimmed milks. Retinyl acetate can also be used.

Because of recommendations of PAG, vitamin A fortification of milk (mainly DSM for developing countries) usually goes together with fortification with vitamin D, which is also a fat-soluble vitamin.

Fortification level: The fortification level of 5,000 IU vitamin A/100 g dry skim milk (about 1,500 μg retinol) is used globally, based on a daily intake of 40–80 g DSM/subject. Adding an average of 20 % is common.

In the US, addition of vitamin A to whole milk is optional, but when added it must be present at a level of 2,000 IU/quart (about 2,100 IU/l). For milks with less fat, addition of vitamin A is mandatory, using the same level. Using the information in the Canadian Food and Drug Act, a recommended fortification level of 1,400–3,000 IU/100 g , can be calculated, which corresponds to a daily intake of 1,200–2,500 IU vitamin A from milk (deMan et al. 1986).

Spring and summer milk has the highest and winter milk the lowest vitamin A activity. To obtain uniform levels of vitamin A, periodic online monitoring and periodic alterations in the level of fortification at the processing plant will be necessary to make up for seasonal fluctuations in the vitamin A level of milk. Different amounts of vitamin A addition for skim milk and low fat milk is also necessary for obtaining uniform levels.

Technology: Process and equipment: Two main methods are usually used for fortifying milk with vitamin A: a dry method and a wet method (Fig. 7-3).

Dry method: For the dry method, skim milk powder is mixed with beadlets of encapsulated vitamin A; therefore, a premix is usually added online to the milk powder after leaving the drying tower just before entering the end cyclone (continuous process), or it can be blended after processing in a separate mixer (batch process). The latter is not common because it requires special machinery.

For the premix, dry-stable vitamin A beadlets (100,000 IU/g) are blended with DSM at a rate of 1:50 to 1:85, resulting in a

premix of 200,000–120,000 IU/100 g. The premix is added to the DSM at a rate of 1:20 to 1:50.

The beadlets are little drops of a vitamin solution in oil, coated with, for example, gum arabic and/or lactose. This coating protects the vitamin against oxidation. These beadlets should never be used in fluid milk; although it has good solubility in cold water (or milk), the vitamin A is very unstable in solution. For this kind of dry fortification, special attention should be given to homogeneity.

Wet method: For the wet method, vitamin A can be added to the thin milk before all processing, or added to the concentrated milk when it has left the vacuum installation (before entering the drying tower). The wet method using concentrated milk is the most common, but both methods show the same retention after processing. Today, it is possible to keep vitamin A stable, notwithstanding the detrimental process conditions during spray drying. For this wet method, an oil-based vitamin A premix is used, stabilized with antioxidants like BHA and BHT. It should be added as an emulsion, therefore, the vitamin is diluted with an oil (for example butter oil or coconut fat) and homogenized in some milk, requiring emulsifiers and a homogenizer. The quality of the fat used is important for vitamin A stability (it should have minimum peroxide value). Any contaminations with copper or oxidation products should be prevented.

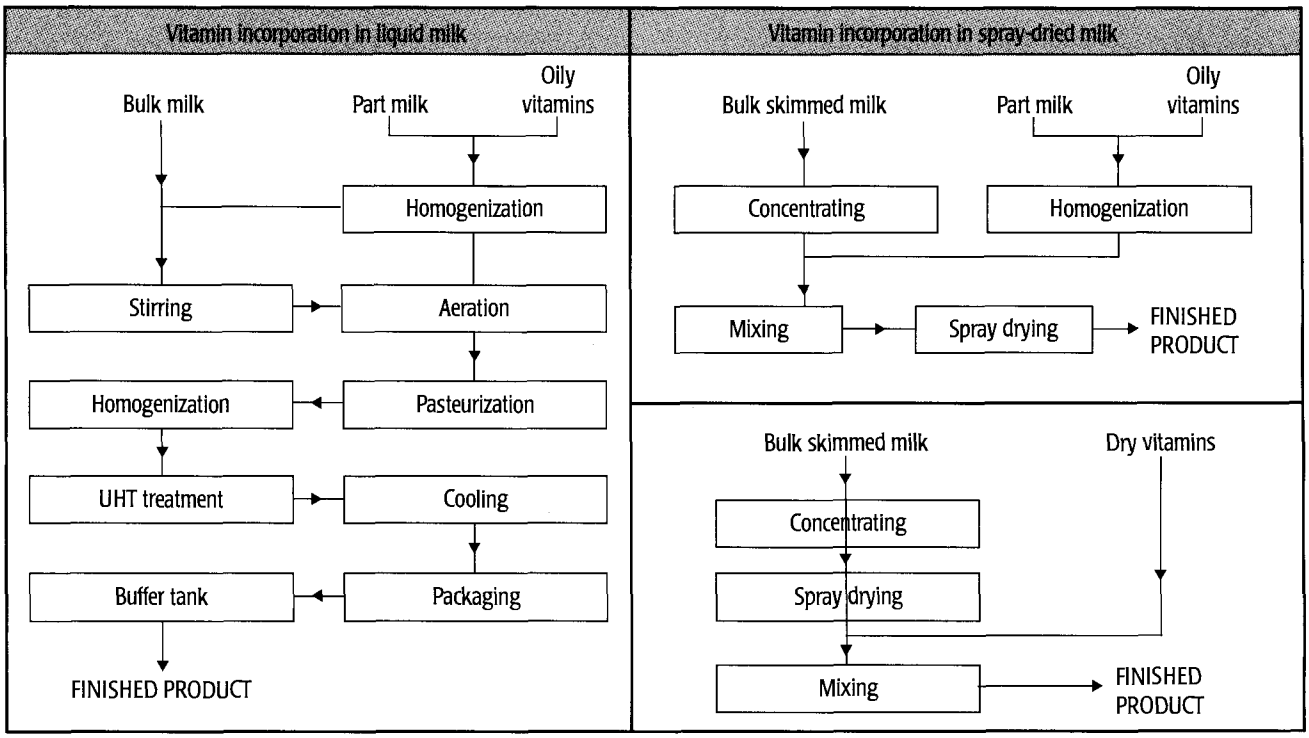
Mol et al. (1976) made an example of manufacturing 4,600 kg DSM: The required amount of vitamin A is diluted in 2 Litres of oil or fat (both at 40–50°C), homogenized in 40 Litres of milk (pressure about 15 MPa), and mixed with a batch of 50,000 kg milk, or added continuously. Finally, the concentrated milk is spray-dried. The amount of added fat is controlled to about 0.1–0.2%, so that the fat content of the product does not exceed permissable levels for skim milk powder. It is important to ensure that no parts of the machinery can cause copper contamination. A disadvantage of the wet method can be that the fat-soluble vitamins could be removed during fat-separation. Karinen (1989) patented such a wet method claiming that used emulsion will not phase separate. Both methods are suitable for fortifying DSM. The dry method seems to result in somewhat more stable vitamin levels, but is also more expensive.

Product: Customers do not have a preference for vitamin A fortified or unfortified milk. Old milk flavours were noticed in stored milk before significant decrease of vitamin A occurred.

Quality aspects: General requirements for a fortified premix for DSM are:

- Homogeneous distribution of vitamin A in the premix;
- Appropriate size and density to prevent segregation;
- Guaranteed and controlled vitamin content;

Fig. 7-3. Flow chart of vitamin incorporation in liquid milk and spray-dried milk.



Source: O'Brien and Robertson, n.d.

- Adequate stability for use in DSM, also in tropical circumstances. After storage for 6 months at 30°C the level of vitamin A should still be above the required level of 5000 IU/100 g; and
- General requirements for human products (directly from Slump (1976).

Rapid test to detect vitamin A: Because not all DSM for food aid is fortified with vitamin A, and this is not always noted on the label, a simple field test to check is described by Dustin (1977). A reagent should, therefore, be prepared by dissolving 50 g crystalline reagent grade trichloroacetic acid in 5 ml distilled water. Heating up to 60°C will assist, the reagent is highly light sensitive. If a few drops of reagent turn blue in a teaspoon of DSM, vitamin A is present. To check for false-negative results 2 x 15 g DSM should be put in 2 cups, 15 ml of water should be added to one and 15 ml reagent to the other. Stir, and if after about a minute, a pale blue or green colour shows up (compared to the blank) vitamin A is present.

The final fortification level is often not controlled enough. This might cause some problems especially with DSM or fluid milk fortified by the wet method. If vitamin A is added to the raw milk, most of the added fat soluble vitamins could be stripped from the milk during fat separation. This also results in excessive vitamin A levels in products with high fat content like cream. Tanner et al. (1988) report that in the US this often results in label claims of vitamin A in low fat and skim milk that do not agree with practice.

Cost and cost effectiveness: The cost of vitamin A fortification of DSM in the 1970s was about $2 per metric tonne. Depending on the price per tonne, this was 0.2–1% of the costs of DSM. For a manufacturing country, it may be much cheaper to enrich all of its food-aid donations than to do it only for those consignments destined to countries or areas where high prevalence of xerophthalmia demands enrichment. The dry method is usually somewhat more expensive than the wet method.

Project/program evaluation: It is known that adequately enriched DSM can effectively prevent xerophthalmia. Current understanding of the disease entails the moral obligation to prevent it wherever a food-aid program provides the opportunity to do so. Such policy will certainly save the sight of many children who might otherwise have been among the 100,000 xerophthalmia-caused cases of blindness every year. (WHO 1976; Dustin 1977).

Observations:

Storage stability of vitamin A in fortified milk powder: Several studies show that it is now possible to manufacture highly stable vitamin A fortified DSM. The wet method seems to result in somewhat less stable DSM, but this difference will not be decisive. Within a year, losses of less than 20% can be expected. In the early storage period (first 6 months), usually the greatest losses can be expected. Many circumstances, however, can cause deviation of this general storage stability. At higher temperatures (>35°C) losses of more than 50% within a year are reported. When humidity increases, especially accompanied with heat, stability dramatically decreases. Exposure to light also has negative effects on vitamin A retention in DSM. Oxygen-free packaging does not really seem to affect vitamin A stability (Bauernfeind and Praman 1964; Mol et al. 1976; DeMan et al. 1986; Woollard and Edmiston 1983).

Storage stability of vitamin A in reconstituted milk: The vitamin A in milk reconstituted from fortified nonfat milkpowder (DSM) is stable for several days, at room and cooling temperature. Only a few percentage loss and little off-flavour were reported. Heating the reconstituted milk up to 30 minutes (common processing in many countries) caused losses of about 20%. Addition of fat can prevent main cooking losses (Anantakrishnan and Conochie 1958; Wilkinson and Conochie 1958; Bauernfeind and Praman 1964).

Storage stability of vitamin A in fortified milk: Defatting has a negative effect on vitamin A stability in fluid milk. Vitamin A stability in low fat milk is better than in skim milk. Exposure to light causes obvious oxidation of vitamin A, resulting in off-flavours. A few days light exposure can reduce vitamin A yield by 30% in whole milk, and up to 95% in skim milk. Addition of ß-carotene can prevent oxidation. Darkness, however, does not guarantee prevention of vitamin A losses, and significant loss (roughly, 20–40%) can always be expected over a period of time. With UHT milk, which can be stored for much longer at higher temperatures than pasteurized milk, losses of 0–70% within half a year are reported, with the greatest loss happening in the first 2 months (DeMan 1981; Woollard and Fairweather 1985; McCarthy et al. 1986; Fellman et al. 1991; Zahar et al. 1992).

RICE (ULTRA RICE)

Rice is the main dietary staple in many populations with vitamin A deficiency. Fortification of rice with vitamin A can, thus, make a significant contribution to prevention and correction of vitamin A deficiency.

Project title: Ultra rice fortified with vitamin A.

Countries: Brazil, Philippines.

Organizations and groups involved: Federal University of Pernambuco, MOH (Brazil); Philippines Food and Nutrition Institute (FNRI), MOH (Philippines); MI (Canada); Bon Dente Nutrition (BDN) (supplier), Iowa State University, PAMM, PATH/USA, USDA, USAID (USA).

Vehicles: Broken rice grains.

Fortificant: Stabilized all-trans retinyl palmitate.

Fortification level: Vitamin A palmitate at a level of 800 µg/g premix.

Technology: Process: Rice flour made from broken rice grains is mixed with a premix containing all-trans retinyl palmitate, a small amount of maize oil, and a fat source for vitamin A stabilization. Previously, lard was used with good results. Recently, coconut and peanut oils have been used to avoid the use of lard and animal fats. Alpha-tocopherol and ascorbic acid are added at 1 mg/g premix (see Fig. 7-4).

Status and results of field trials: Laboratory tests (Brazil, Philippines).

Product: The reconstituted broken rice is not distinguishable from whole rice grains. The recent results of an informal taste test of vitamin A-fortified ultra rice in Indonesia showed that the 10 tasters were able to detect differences between two types of rice used (Rojolete and Bulog), but only two out of 10 were able to detect differences between fortified and nonfortified samples.

Quality aspects: The vitamin A proved stable to storage and cooking. The enriched rice proved to be nontoxic and had the same sensory characteristics of ordinary rice. Some advantages of ultra rice are that it is cooking quicker, can be augmented with flavours, spiced, and will last for hours on a steam table.

Cost and cost effectiveness: When local production is established and depending on production quantities, the local retail price of fortified rice is estimated at US$0.20/person per year. If the premix has to be imported from the US, the retail price is estimated at US$0.30/person per year.

Project/program evaluation: Bioavailability studies have been conducted in Brazil. Similar confirming tests are under way in the Philippines. Results indicate that the bioavailability is good. Storage tests indicate that vitamin A half life will be a year or more. Under an MI-funded pilot project, the feasibility of introducing ultra rice in one area in Indonesia is under investigation.

Because rice is a staple that is produced, milled, and consumed under conditions that vary from community to community, the delivery of vitamin A-fortified rice will not be simple, and only a carefully developed public health initiative is likely to meet with success. This initiative must include IEC (information, education, communications), public policy dialogue, interactions with local NGOs, social marketing, and all the other tools to assist introduction, implementation, and sustainability of such activities.

Observations: It is the goal of Bon Dente (BDN) to support the transfer of technology to developing countries to provide a local source of supply as well as minimize production costs.

Future requirements/developments: Ambitious plans for a major test-market introduction in Indonesia and Brazil have been well received by the government officials, but not yet approved. Initially, ultra rice will be fortified with vitamin A. Preliminary laboratory tests have been successfully completed with iron and iodine. Multiple fortification is being explored. The technology is also applicable to mixers of maize and ultra rice to make a higher protein product.

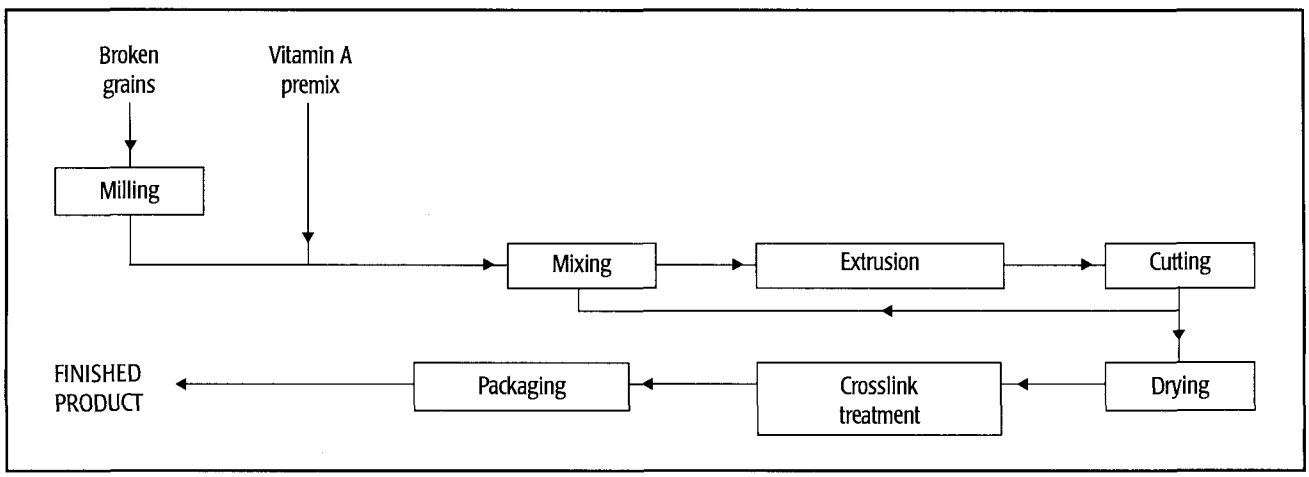
TEA

The first suggestion of using tea as a vehicle for vitamin A fortification is described in a US patent of 1943 (Buxton and Harrison 1943).

Countries: Pakistan, India, Tanzania.

Organizations and groups involved: India: USAID, New Delhi (experiments carried out in 1971/1972); Pakistan: Government of Pakistan, USAID (experiments carried out in 1973/1974); Tanzania: TFNC, Ministry of Minerals, Water and Energy, MOH, Muhimbili Medical Centre, Tea Authority, Tanzania Tea Blenders, UNICEF (Tanzania); Uppsala University (Sweden), IAC (Wageningen); and PAMM (Atlanta) (Temalilwa and Momburi 1992).

Fig. 7-4. Flow chart of production of ultra rice fortified with vitamin A.



Target group:

India: The entire Indian population. Of the total estimated population of 15.9 million in the age group of 0–4 years (UN population projection in 1995) 86.9 million are at risk of vitamin A deficiency (WHO 1995).

Pakistan: The children and pregnant women of the lower income groups. The nutrition survey of West Pakistan indicated an apparent deficiency in Vitamin A in the Pakistan diet, especially among the children and pregnant and lactating women of the lower income groups.

Tanzania: The entire population of Tanzania. The sentinel xerophthalmia surveillance system (started in 1982) discloses a severe VAD in children under five. Of the children under five, 30% are affected and of the total population 6%.

Vehicles: Nutrition surveys in several of the Indian states revealed that tea is the obvious vehicle for a large-scale food-fortification program. It meets all the general criteria for a suitable vehicle.

Researches in several of the Indian states have pointed out the following characteristics. Tea is the national drink, consumed by all age groups, irrespective of socioeconomic status, and in both rural and urban areas. Even very young children are given 1–2 cups of tea per day. The price of the consumer product is sufficiently high to absorb the costs of the added nutrient. The stability of the vitamin A during processing and in the finished product is high (Brooke and Cort 1972). In Pakistan, an additional criterion was formulated – supplies (except vitamin A) and machines are to be available in the national market (Fuller et al. 1974). In India, Pakistan, and Tanzania tea is centrally produced or processed.

The tea to be fortified was of two grades. First, is tea dust (the term dust refers to the size of the tea particles, which consist of the smallest particles secured in the grading process excluded the waste products, i.e., fluff and chalk). Tea dust is used to provide a strong, dark brew or it is blended with broken grades. Second, is tea leaves used to provide a light or pale colour and flavoury brew.

Fortificants: The characteristics of four types of vitamin A fortificant were tested:

- Powder: Retinol palmitate 250-SD from Hoffmann-La Roche (water dispersible), a palmitate esther of vitamin A at 250,000 IU/g. It is a fine, dry, stabilized white powder, containing 250,000 IU of vitamin A per gram.
- Of the retinol palmitate 250-SD powder and of vitamin A acetate an emulsion of retinol palmitate in an acacia and water-based solution at 400,000 IU/g was made to be used for fortifying tea leaves. (The Pakistan investigators report this emulsion containing BHT and dl-alpha-tocopherol as antioxidants and sodium benzoate as preservative.)
- To provide a fortification solution with a content of 10,000 IU vitamin A/g tea the emulsion was diluted (2 g of emulsion plus 98 g of solution) in water, in a 20% dextrin solution and in a 50% sucrose solution. The results are summarized in Table 7-12.

For stability reasons, the 50% sucrose solution was chosen as the best medium for dilution of the palmitate or acetate emulsion. Stability of the vitamin A solutions in the final product was tested using palmitate 250-SD powder for tea dust and a water-soluble oil of vitamin A palmitate, a palmitate emulsion, and an acetate emulsion. The retention of the vitamin A in tea after 5 minutes of boiling time and one hour of boiling time was 100% for both the palmitate (both the powdered form and the diluted emulsion form).

The investigators in Pakistan included segregation tests, shipping tests, brewing tests, (accelerated) storage tests, and taste tests performed by a professional panel of experienced tasters in the laboratory phase and the pilot phase of the program. No organoleptic differences between fortified tea (at levels of 125, 250, 375, and 1,125 IU/cup) could be determined by the taste panel.

Fortification level: The target level of fortification was set at 125 IU/g for vitamin A per cup of brewed tea. This target was based on the assumption that for the production of one cup (150 ml) of brew, 3 g of dry tea materials are used. Daily consumption of tea was established at 3 cups/person. Thus, the fortified tea would supply 1,125 IUs of vitamin A, about 40% of the average RDA (according to the 1970 Nutrition Survey of West Pakistan). The 1972 RDA for India, are 1,000 IU/day for children and 2,500 IU/day for age 16 and up. A child given 1–2 cups of tea per day would thus receive 375–750 IU/day, an adult would ingest about 45% of the average RDA (Brooke and Cort 1972). About 27% of the vitamin A from the fortified tea was available within 5 minutes of brewing.

Storage tests in Pakistan showed an average loss of vitamin A of about 47% after 12 weeks of storage. The initial fortification level should compensate for these losses. The tea was, therefore, fortified at 250 IU/g. The level of antioxidant is decisive for the relatively high stability of the Pakistan product (Paden et al. 1979).

Technology: Process and equipment:

The technology developed in India for the fortification of tea was:

- Dry mixing of tea dust and vitamin A Palmitate 250-SD, and
- Spray mixing of the diluted emulsion by spraying the solution onto the tea as it emerges from the drying chamber and subsequently drying at 60°C during one hour.

Table 7-12. Stability tests of vitamin A fortificants in tea dust and tea leaves.

Tea type	Form of vitamin A	Application	Storage conditions	Retentation %
Dust	Palmitate 250 SD powder	Dry mixing	1 yr, room temperature	85
Leaves	Palmitate or acetate emulsion in water	Sprayed	1 mth, room temperature	50
Leaves	Palmitate or acetate emulsion diluted in 20% dextrin solution	Sprayed	1 mth, room temperature	85
Leaves	Same	Sprayed	6 mth, room temperature	43
Leaves	Same	Sprayed	6 mth, 37°C	20
Leaves	Palmitate or acetate emulsion diluted in 50% sucrose solution	Sprayed	1 mth, 37°C	98
Leaves	Same	Sprayed	6 mth, 37°C	90

Source: Brooke and Cort (1972).

The technology tested in Pakistan for the fortification of tea was:

- Dry mixing of tea and powdered vitamin A,
- Spraying tea material with glycerine (adhesive) and subsequent dry mixing of tea and powdered vitamin A,
- Spraying a vitamin A emulsion diluted in a cottonseed oil solution onto tea material, and
- Spraying a vitamin A emulsion diluted in a 50% sucrose solution onto tea material.

As a result of the test in Pakistan the following tea fortification process was developed.

Batch production of a fortified tea concentrate in a pan coater:

- Dilution of 25 g vitamin A emulsion in 75 g of 50% sucrose to produce the vitamin A spray solution, and
- Air spraying of 25 g of the spray solution onto 975 g of tea material in a pan coater (45 seconds, air spray gun) to produce the fortified tea concentrate.

The fortified tea concentrate (100 g at 2,500 IU/g) was used as the vitamin A carrier to be one of the inputs for a tea blend. The fortification of the final product was carried out in a PK twin-shell blender during a blending time of one hour.

The technology of dry blending tea material or tea material plus glycerine was abandoned due to excessive segregation. The fortified tea plus glycerine showed a lower level of segregation than the fortified dry tea. This process, however, requires the application of two unit operations to arrive at the desired product, whereas the vitamin A emulsion in 50% sucrose requires one unit operation only. Figure 7-5 shows a flow chart of vitamin A enriched tea manufacturing.

The vitamin A-cottonseed application was rejected for organoleptic reasons; the final brew yielded an oily appearance. The oil-spray process was discarded also for occupational safety reasons (dispersed oil being potentially explosive).

Status:

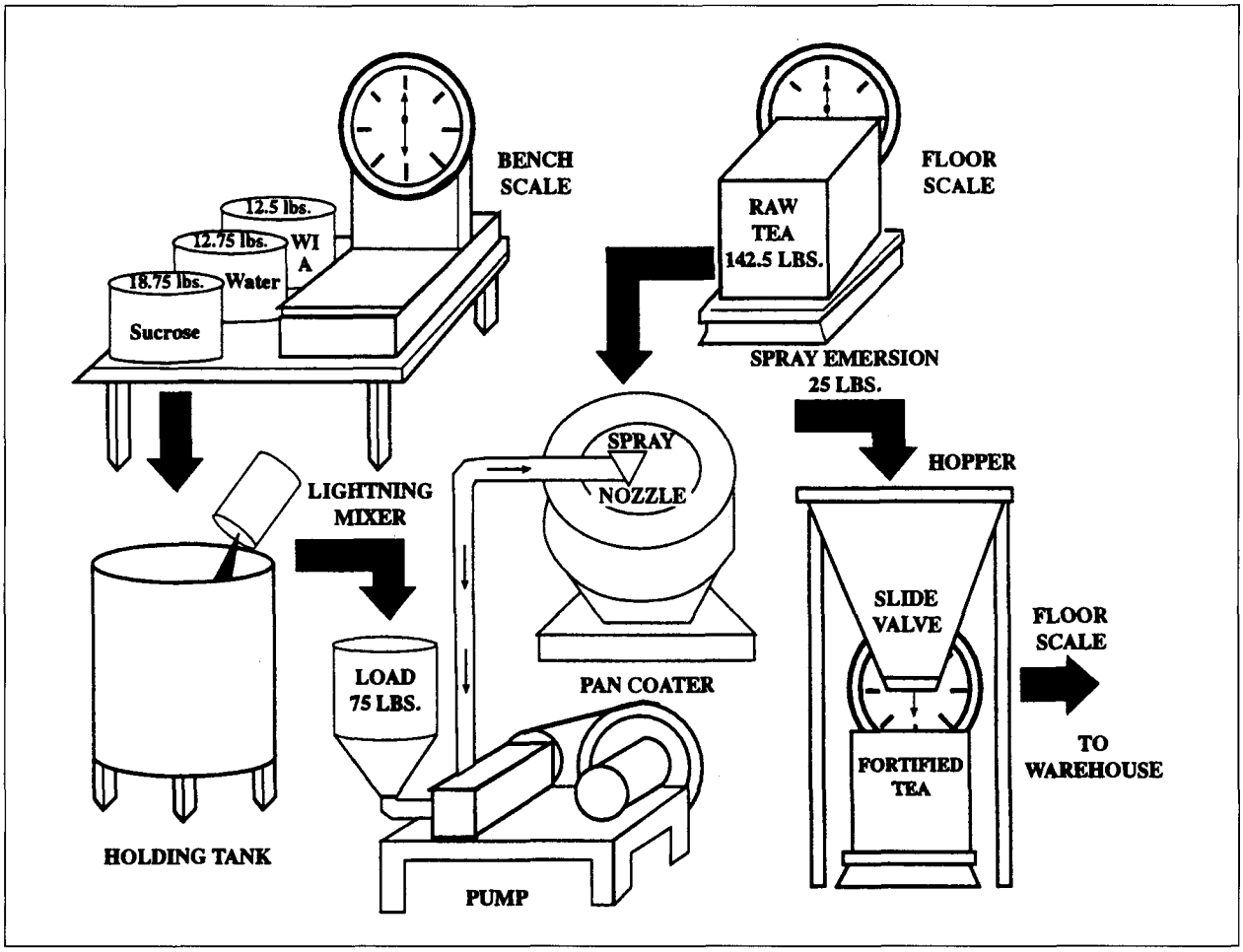
India: Laboratory tests have resulted in the development of the fortificant and the processing technology. Pilot trials on a commercial scale and a producer and consumer acceptance survey have been finished. Taste panels from the tea producing industry and consumer taste panels were not able to detect any difference in taste, odour, colour, clarity, or other characteristics of the brewed tea. No regional or national field trials have been reported.

Pakistan: Laboratory tests and pilot plant tests have been completed. The results have been presented on a model scale to tea-processing manufacturers throughout the country. Detailed process descriptions, production characteristics, and plant definitions for several production capacities have been prepared as well as the housing, equipment, and operating costs budgets.

A project implementation strategy was developed in which four private tea-processing enterprises would participate. Before implementation, investigations into tea purchase and consumption behaviour and vitamin A status of children and pregnant women will assist in establishing the fortification level. The industrial project will be complemented by research into storage under industrial production conditions, effect on the vitamin A status in the sample population, and industrial-scale production feasibility. Although the technology developed is very promising in terms of costs of fortification and incorporation in local production facilities, no further mention of the project has appeared in the international literature.

Tanzania: The project in Tanzania is still being formulated. The cooperation of the tea industry has been gained in the very

Fig. 7-5. Diagrammatic flow sheet for fortification of tea with vitamin A.



first stage of the program. Test runs in the tea plant and development of the proper packaging and labelling is now in progress.

Future requirements/developments: When considering vitamin A fortification of tea, a note of caution should be made. Drinking tannin-containing beverages (tea) with meals may contribute to the development of iron deficiency if the diet consists largely of vegetable foodstuffs (Disler et al. 1975).

MONOSODIUM GLUTAMATE (MSG)

Countries: The Philippines, Indonesia.

Organizations and groups involved: MOH, Union Chemicals (The Philippines); MOH, PT Sasa Inti (Indonesia); the Coating Place, Iowa State University, Helen Keller Int, (USA).

Target group: In the Philippines, the baseline survey indicated a high prevalence of low or deficient serum vitamin A levels (47% of the children between one and 16 years of age). Some 4.5% of the children between one and 16 years of age showed clinical signs of xerophthalmia. The first MSG-fortification field trial was conducted in the island of Cebu. This small-scale field trial was followed by a tri-provinces field trial (Solon et al. 1984).

In Indonesia, the national xerophthalmia survey of 1978 showed xerophthalmia and vitamin A deficiency as a significant public health problem, way below the WHO limit for defining the presence of a significant public health problem. Almost 0.64 per 1,000 preschool children suffered from severe blinding eye disease as a result of vitamin A deficiency, one per 100 suffered from mild xerophthalmia, and a majority of the children had a low vitamin A status.

Vehicles: MSG ($C_5H_8NO_4.Na.H_2O$) is a crystalline, "snow-white" product, difficult to fortify because of moisture retention and discoloration. The MSG particles are large, elongated ("needle") crystals. When shaken, the product produces a crystalline sound indicating a dry, free-flowing content, which is considered to be an important marketing characteristic.

In the Philippines, three products (salt, flour, and MSG) were candidates for food fortification because of their consumption frequency, and MSG was found suitable for food fortification (Bauernfeind 1991) because it is centrally produced. Only two manufacturers produce MSG, of which one produces 95% of the total marketed production. Food-frequency surveys showed that, on average, 94% of the children consumed MSG at least once a week. The MSG was sold in packages of 2–4 g.

Families consume an average of two packages a day, with a maximum of three packages a day. MSG consumption does not influence salt consumption patterns (Solon et al. 1979).

In Indonesia, four products (white sugar, flour, MSG, and salt) were candidates for the vitamin A fortification project and, among them, MSG had most of the general criteria required (Muhilal 1984, 1988a, 1989).

The selection criteria in both the Philippines and Indonesia can be summarized as follows:

- Produced centrally (therefore, fortification can be centrally controlled and monitored);
- Reaches the largest proportion of the target children;
- Consumed in substantial amounts by the target children;
- Consumed with relatively small variation;
- Permits an adequate fortification level without affecting the consumer acceptance;
- Marketed in small packages to the families at risk, which enabled targeted fortification to the poorest and highest risk (low social and economic) segments of society;
- Sanitary handling and some environmental protection (marketed in small plastic sachets); and
- A short turnover period.

Flour and sugar consumption was highly variable, and there was no specially sized package targeted at the high-risk families in the market. Both flour and sugar were rejected as vehicles because of the difficulties in defining the fortification level. Salt was rejected because this vehicle was already "claimed" in the iodization program and because of its highly hygroscopic character, which would affect the vitamin A stability (Muhilal 1988b, 1989).

MSG is generally considered a safe additive. The maximum permissible daily intake is 150 mg/kg body weight (WHO 1974). When added to food as an enhancer, there is an optimal concentration (up to 0.8% of a food, by weight). As the palatability of the food decreases beyond this concentration, the use is self-limiting (Bauernfeind 1991). The average consumption of MSG for preschool children was 18 mg/kg body weight, and the maximum recorded intakes rarely exceed 85 mg/kg body weight.

Turnover of the product is generally in the range of between 2 and 4 months. The product reaches the consumer about 2 months after the manufacturing date (Solon et al. 1985).

Fortificants:

The Philippines: The fortificant chosen for the Cebu field trial was a dry vitamin A 250-SD (vitamin A palmitate 250-SD, 250,000 IU/g Hoffmann-LaRoche). The average potency loss was 3% per month during the first 6 months. After this period, potency losses were markedly declined.

As some objections against the powdered, fortified MSG arose during the Cebu field trial, the fortificant chosen for the second tri-provinces field trial was a dry vitamin A beadlet (vitamin A acetate 325L, 325,000 IU/g Hoffmann-LaRoche). The vitamin A 325L is less soluble than the vitamin A 250-SD.

Indonesia: The fortificant chosen for the field trial was 250-CWS (250,000 IU/g, cold-water storage, Hoffman-La Roche), yellowish beadlets.

MSG is marketed in Indonesia as a perfectly white, crystalline powder. As a result, the slightly yellowish colour of the vitamin A fortificant should not be visible, and a technology to produce "white" vitamin A particles, not detectable in the final product was developed. To mask the yellow colour of the fortificant, the powder was coated with finely ground MSG dust (Muhilal 1988a). A more recent development was the production of "white" vitamin A by coating the beadlets with white titanium dioxide (Muhilal 1989).

To produce the premix, 800 g of vitamin A 250-CWS was mixed with 60 g of hydroxypropyl cellulose dissolved in 450 ml ethyl alcohol (to serve as binding agent). To this mixture was added 3,200 g of 100-mesh MSG powder, so that the MSG powder would stick to the vitamin A, and the final premix was dried by fanning. The resulting premix was "dust free" and free flowing.

The premix was combined with commercial grade MSG in a ratio of 5:95 and mixed until homogeneous. The final fortified product contained about 3,000 IU of vitamin A/g (Muhilal 1988b).

Vitamin A 250-CWS is sensitive to oxygen, high temperatures, moisture, and light. It retains more than 50% of its potency when stored for more 18 months at 25°C and for more than 7 months under dark, humid conditions.

Fortification level:

The Philippines: The fortification level chosen for the Cebu and the tri-provinces field trials was 15,000 IU vitamin A/ package of 2.4 g MSG. Because of manufacturing constraints, the variation in the mean vitamin A content of the sachets at various points of the distribution chain is significant. Under the normal marketing and environmental conditions, however, the level of fortification can be reasonably maintained.

Indonesia: The vitamin A consumption survey revealed a dietary intake of vitamin A equivalent to 700 IU/day. Main sources were green leafy vegetables and oil. The fortified MSG should contain sufficient vitamin A to provide between 25% and 50% of the RDA. Given a consumption of 0.23 ± 0.20 g MSG/day, the fortification level was set at 700 IU/0.23g MSG.

Technology/process conditions:

The Philippines: To overcome segregation problems due to physiochemical differences of the MSG crystals and the vitamin A, the MSG was reduced in size (100 mesh) and a free-flowing agent was added. All ingredients were blended in a Nauta mixer and the final product was heat sealed in plastic sachets.

In the second (tri-provinces) field trial, the manufacturer did not consider the total amount of fortified product as justification for the installation of new mixing equipment. Mixing was, therefore, a manual process. The vitamin A 325L beadlets were weighed in a polyethylene bag together with the MSG. The bag was tumbled until even distribution of the components was achieved. The content was then gravity fed through the chute of the packaging machine for sachet filling and sealing. This choice of technology suggests a rather large variability in vitamin A concentration per package.

Indonesia: Before the beginning of the field trials, cooperation was sought from the MSG manufacturing industry. The company that controlled 80% of the market in the test area, PT Sasa Inti, Surabaya, was willing to cooperate on the condition that falling sales volumes would entitle the company to withdraw from the program.

The premix was mixed with commercial grade MSG crystals, using a Patterson Kelly blender (East Stroudsburg, PA) until the fortified product was homogeneous.

Product:

The Philippines: During the Cebu field trial some objections to the quality of the fortified product arose, from the point of view of the MSG producer:

- The fine particles of the MSG could cause fouling of the seals, thus causing a higher percentage of rejects and/ or caking of the product; and
- The producer preferred the needle-like large crystals over the powder form of the milled fortified product.

The MSG fortified with the vitamin A 325L beadlets in a batch mixing process showed a larger degree of inhomogeneity than the powdered fortified product and a tendency to segregation. The package size, however, and the large number of packages purchased over a long-term, should approach the average desirable fortification level, and the experimental product was considered adequate for the field trial. The labelling on the packages was similar to the labelling on the regular MSG with the exception of adding +A to the brand name (Aji-no-moto+A) and stating the fortification level of 15,000 IU vitamin A.

The process conditions in the tri-provinces field trial (mixing the dust-free vitamin A premix with MSG crystals) guaranteed the watertight heat seal of the plastic packages. This improves the stability of the vitamin A under normal marketing conditions. Stability of the vitamin A in the fortified product showed a retention of 80% after 2 months and a retention of 50% after 11 months. When the product is protected from light, the fortified MSG showed a retention of 50% after 2 years of storage at 35°C. Turnover rates of the product are 2–4 months. The level of fortification at the point of consumption, therefore, is satisfactory.

The standard deviation of mean vitamin A content at the point of processing indicated some problems with the homogeneity of the product. The package size, however, and the large number of packages purchased over a long term should approach the average desirable fortification level.

One of the problems that had to be solved was the masking of the yellow colour of the vitamin A in the white MSG. The marketing and distribution figures from the producer showed no change in sales of the fortified product after the start of the field trial. Neither did consumption of the fortified product change. The constant sales volumes proved that the fortified product did not differ in organoleptic qualities from the nonfortified product.

Quality aspects: In further field trials in Indonesia under the auspices of HKI in 1989, problems with regard to the stability of the white coating (and thus the white colour of the MSG-A) evolved. A newly developed white coating did result in a dramatic impairment of vitamin A potency. It was discovered that the white vitamin A beadlets should approximate the size of the MSG crystals. An agglomeration step in the production process of the premix had to be developed. In the following years, new vitamin A prototypes and new coatings have been tested for bioavailability; stability; resistance to moisture, heat, and light; dissolvability; and organoleptic characteristics. Blending of the white vitamin A and the MSG need special attention as the vitamin A is only 2% of the final product (Wilbur 1991).

Marketing/distribution channels: The fortified MSG was marketed in the same package size as the nonfortified product, along the normal marketing/distribution channels of the manufacturer in the test area. The label mentioned the addition of vitamin A to the product as MSG-A.

Cost and cost effectiveness: The target of the program will be fortification of 35–50% of the MSG that reaches the rural areas. There will be a difference in price between the fortified and the nonfortified MSG. The initial subsidy will gradually be withdrawn and the cost of fortification of the MSG will pass on to the consumer of all MSG produced, regardless of package size. The actual costs of fortification, 13% of the cost of the nonfortified product, will be spread over all consumers, thus increasing the costs of the MSG and MSG-A by a marginal 7% over a period of several years.

Project/program evaluation: The results of the field trials in both the Philippines and Indonesia showed multiple benefits for preschool children:

- Improvement in serum retinol levels,
- Reduction in the low and deficient serum retinol levels,
- Reduction in the prevalence of xerophthalmia,
- Improvement in growth,
- Increase in haemoglobin level, and
- Reduction in the mortality rate.

Not all the children in the field trial area consumed MSG, and of those who did, 20% did not receive the fortified brand. Mandatory fortification of all MSG marketed to poor, rural communities should have an even greater positive impact on health, growth, and survival of the children.

In the phase following the field trials in Indonesia (1987–1991), the marketing of fortified MSG will be expanded. The different industries that will have to cooperate in a nation-wide fortification program will thus become familiar with the production and marketing of MSG-A and adapt their production procedures in time, before a national fortification project is started.

The logical continuation of the program would be a full-scale MSG fortification program aimed at the poor rural areas. Unfortunately, the safety of MSG as a vehicle has been subject to debate. Furthermore, manufacturers were reluctant to introduce the technology because of their doubts that the process would guarantee a sufficiently white product.

Observations: The pioneering work done in the Philippines and in Indonesia has demonstrated that fortification of MSG and marketing the fortified product through the normal channels can be an effective strategy for controlling VAD. The MSG fortification project in Indonesia is an example of a successful food-fortification program in progress, although it has not yet been implemented on a nation-wide scale. Issues related to MSG as a carrier and associated health results, however, remain to be solved. Most importantly from the industrialists' point of view is that the project is not dependent on the good will of industry to cooperate, but it is designed to become financially self-supporting after the initial years of subsidy. For those countries in Asia where VAD is a public health problem, fortification of MSG can be an adequate strategy that could be implemented in a relatively short period using the experiences of the Philippine and Indonesia trials.

OTHER VEHICLES

Cereal grain products:

Abstract: In 1974, the Food and Nutrition Board of the National Research Council of the US proposed a new fortification formula for cereal grain products (wheat flour, semolina (from durum), maize flour, maize meal). Vitamin A was added as retinol palmitate or dry retinyl palmitate. The added level was 5,000 IU/pound of flour, which is a 15% average of the NAS fortification level of 4,333 IU/pound (= 1.3 retinol equivalents). No vitamin A is originally found in flour, with the exception of maize flour that contains some provitamin A activity from carotenoids (Parrish et al. 1980).

The carrier for vitamin A was maize starch, about 40% of the premix weight. Vitamin and mineral enrichment materials were premixed with 5 pounds of flour by "fluidizing" (shaking) in a closed plastic bag filled with air. Flours were mixed in 100 or 200 pounds lots in a Wenger double-ribbon horizontal batch mixer. Equally divided portions of the premix were distributed on the top of each 50 pounds of flour after it was spread out in the mixer. Flour and premix were blended for 15 minutes (Parrish et al. 1980).

It is also possible to add fortification materials during flour making in a production mill. Parrish et al. (1980) used a Sterwin enrichment feeder and found no differences in vitamin A content compared to the mixing method.

Losses of vitamin A during storage of flours (made of wheat and durum) were up to 10% in 6 months at cooling and room temperature (i.e., 3°C and 21–32°C). Losses in maize flour and meal were a little more – over 20%. An average of 15% of the proposed levels might be more than needed under normal conditions. Storage at 40°C showed losses of about 50% in all flours.

This is confirmed by other workers, but the loss stabilizes probably after 3 months. Yellow maize contains natural carotenoids with provitamin A activity. Their loss during storage tests was about twice that of stabilized vitamin A (Parrish et al. 1978, 1980).

The bioactivity of the remaining vitamin A did not change during storage (Lan-Ing Liu and Parrish 1989). No losses were reported during pneumatic conveying or simulated shipping and handling (Parrish et al. 1980).

Wheat, the least preferred staple in Bangladesh, is generally eaten by the very poor. Wheat aid goes to the particularly disadvantaged through programs targeted at those most in need. The mixing of synthetic vitamin A powder with wheat flour has been considered but rejected as inappropriate because Bangladeshi households tend to buy locally milled whole wheat grain in the market. Thus, fortification of whole wheat with vitamin A was considered. A premix of concentrated vitamin A attached to wheat grain was added to the regular grain in the proportions 1:400. But the project to demonstrate the technical feasibility of fortification and its nutritional impact was not approved by the government (Nestel 1993).

Peanut butter:

Abstract: As early as 1954, experiments were carried out in the US to fortify peanut butter with vitamin A palmitate. The

peanut butter prepared contained hydrogenated peanut oil, salt, and peroxide-free peanut oil. Synthetic vitamin A palmitate was dissolved in peanut oil in an amount calculated to ensure at least 71 USP units of vitamin A/g of peanut butter. First-grade, shelled peanuts were roasted, split-blanched, and sorted. Through special feeders, the materials were delivered to the grinder. Differences in temperature of processing 140–180°F (60–82°C) were not found to have an appreciable effect on the content of vitamin. The content of the vitamin A incorporated in the peanut butter was found to remain satisfactorily high, although reduced, after storage of the product for 6 months at 80–100°F (27–38°C) (Willich et al. 1954).

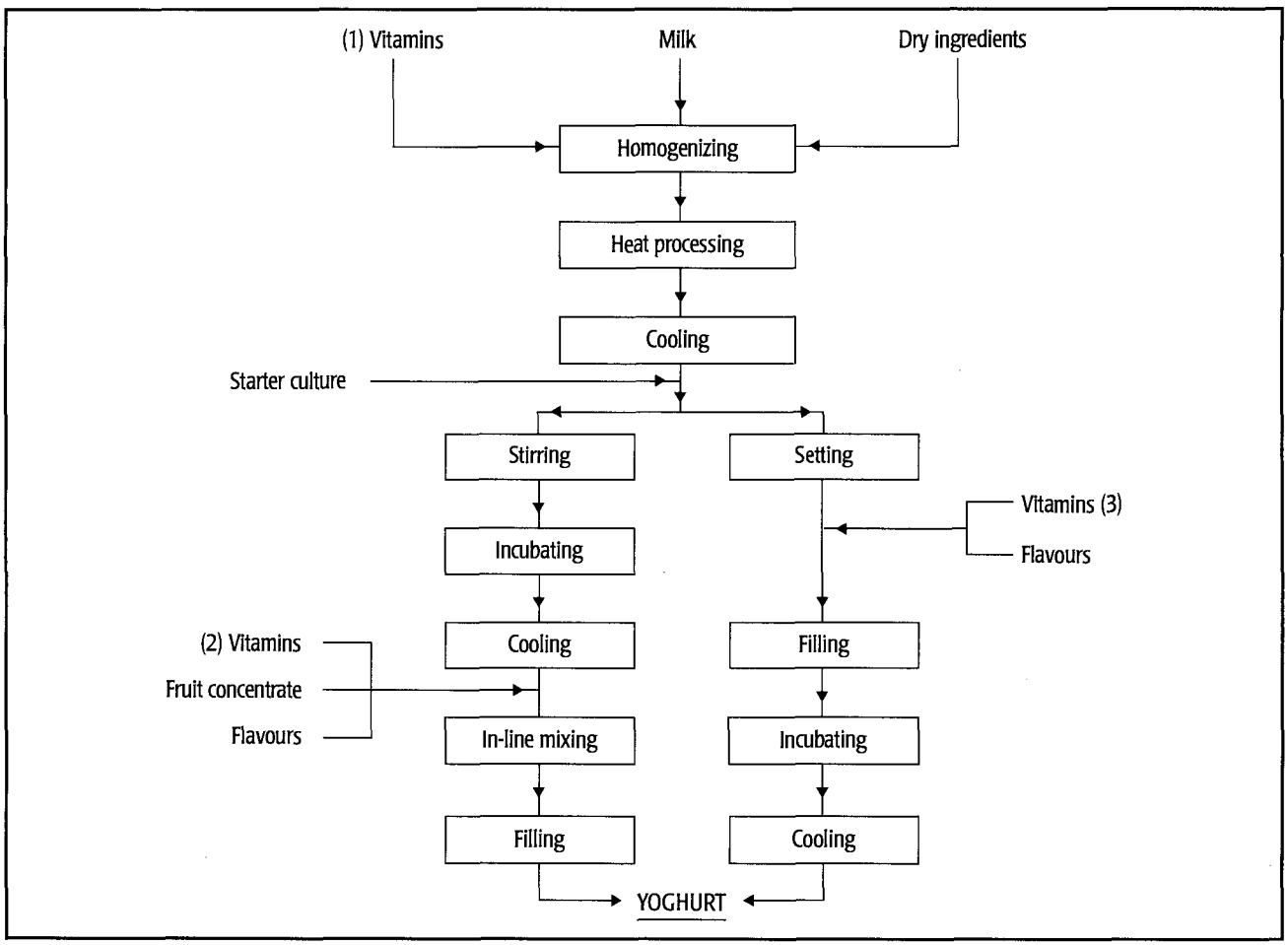
Salt:

Abstract: Fortification of salt with vitamin A has been tried under laboratory conditions. The fortificant used was dry vitamin A palmitate Type 250-SD protected by a lipid. For a moisture content lower than 2%, the protection of vitamin A activity was satisfactory. Administration of salt fortified with vitamin A in a concentration of 440 IU/g of salt over a 6-month period was found to be effective in improving vitamin A status among preschool-age children. Impurities in the salt and nonuniform crystals destabilize vitamin A. Because salt is hygroscopic, it must contain a desiccant and/or must be packaged in a moisture-resistant container to prevent it from absorbing moisture (Nestel 1993).

Yoghurt:

Abstract: Plain and raspberry-flavoured low-fat yoghurt samples were fortified with various commercial forms of vitamins A and C under actual production conditions (Ilic and Ashoor 1988) (see Fig. 7-6). Immediately after processing, yoghurt samples were kept at 3°C for 6 weeks and were analyzed biweekly for pH, titratable acidity, and vitamins A and C. Data revealed that both vitamins decreased gradually in fortified yoghurt with vitamin C decreasing at a higher rate than vitamin A. At a level of fortification of 10,000 IU of vitamin A, however, and 300 mg of vitamin C per 227 g container of plain or flavoured yoghurt provided at least 100% of the US RDA up to 6 weeks of storage at 3°C. This level of fortification did not significantly change pH, titratable acidity, or sensory characteristics of yoghurt samples. After 6 weeks of storage, however, a light yellow taint was noted in plain yoghurt samples fortified with vitamin C or with vitamin A+C.

Fig. 7-6. Flow chart of yoghurt production and points of vitamin addition.



Source: O'Brien and Roberton, n.d.

The taint was absent in yoghurt fortified with vitamin A alone or in raspberry-flavoured yoghurt fortified with vitamin C, vitamin A, or both.

Dependent on the method of manufacturing to fortify the product and preferred stage of addition of vitamins, there are a number of possible routes. Temperatures and times of processing vary from process to process. The two basic methods of adding vitamin A to yoghurt are:

- Addition as a dry premix to the base ingredient at initial mixing stage, and
- Addition to the fruit conserve via the fruit supplier.

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8. OPPORTUNITIES FOR MULTIPLE FORTIFICATION

DOUBLE FORTIFICATION WITH IODINE AND IRON

SALT

Countries: India, Thailand, Canada.

Organizations and groups involved: National Institute of Nutrition (India); Department of Radiology, Mahidol University, MOH (Thailand); MI, and University of Toronto (Canada).

Target group: The product could be made available universally to large populations or targeted at particular consumers or customers, and through special delivery channels, e.g., for pregnant women and young children.

Vehicles: From the standpoint of fortification, the quality of salt in developing countries would broadly fall under the following three categories:

- ***Refined:*** The salt is already refined and well packed to match the requirements for fortification .
- ***Semirefined:*** The salt is partially refined but does not meet specifications for fortification .
- ***Unrefined:*** The salt is not refined.

Fortificants: Mannar et al. (1989) reported that ferrous fumarate and potassium iodide represent a workable combination without stabilizers. Salt fortified with ferrous fumarate and potassium iodide is of a very light brownish colour and does not deteriorate over time, provided it is kept sealed in waterproof packing. The formula proposed is ferrous fumarate 3,200 ppm (Iron content 1,000 ppm); Potassium iodide 65 ppm (Iodine content 50 ppm).

Narasinga Rao (1990) has proposed a formula using ferrous sulphate(1000 ppm Fe), potassium iodide (20 ppm Iodine) and a stabilizer (a chelating polyphosphate). He has reported that the bioavailability and stability of the double-fortified salt under different conditions of storage and acceptability were found to be good. The formula proposed by Rao is Ferrous Sulphate 3,200 ppm; Potassium Iodide 40 ppm; Stabilizer (Sodium hexameta-phosphate 1%).

The National Institute of Nutrition (NIN) has recently reported (V. Reddy, Personal communication) that a dry mixing technique was found superior to the spray mixing technique used earlier to mix the additives with the salt.

Work done by Diosady and others at the University of Toronto (unpublished) has shown that the NIN formula ($FeSO_4$ + SHMP + KIO_3) works well in pure salt but shows heavy iodine losses in the presence of magnesium chloride impurity in the salt. It has been determined that encapsulation of the potassium iodate with SHMP improves iodine retention to 73% after 6 months. If, however, magnesium chloride is present, the samples discolour.

The University of Toronto has recently developed a stable formulation of salt (double fortified with iodine and iron) under a study sponsored by MI and the International Development Research Centre (IDRC) (L.L. Diosady, personal communication).

A new technique of dextrin microencapsulation has helped create a barrier between the iron and iodine compounds (ferrous fumarate and potassium iodate) and retain them in stable form under varying environmental conditions. In vitro and in vivo studies on this formulation to test their absorption are under way and will be followed by a multicentric field trial to assess their impact on iodine and iron status and consumer acceptability.

Fortification level: Rao (1990) proposed a mixture of $FeSO_4$ (3,200 ppm), KI (40 ppm), and polyphosphate (1%), which provides 1,000 ppm Fe and 20 ppm I_2. Mannar et al. (1979) proposed a mixture of ferrous fumarate (3,200 ppm) and KI (65 ppm), which provides 1,000 ppm Fe and 50 ppm I_2.

Technology: Process and equipment: The hydromilling process (Fig 7-1) is commonly used for refining the salt. This is essentially a physical upgrading process in which the salt is ground and washed several times using saturated brine. This process produces a product that is comparable in most respects to recrystallized salt and, to a customer, the difference between the two varieties may be indistinguishable.

The processing required for different grades of salt is: For *unrefined* – grinding and washing, centrifuging and drying, fortification and packaging; for *semirefined* – centrifuging and drying, fortification and packaging; and for *refined* – fortification and packaging. For a detailed description of each process see Chapter 7 under "Single Fortification with Iodine."

Status: A pilot fortification program in the northeast region in Thailand was proposed in 1979, but its implementation has not been reported. The fortified product was available on a large scale, but an effective distribution and educational system was lacking. Moreover, universal fortification was not considered a suitable approach due to financial constraints and possible iron overload for the healthy part of the population.

National Institute of Nutrition (NIN) proposes to conduct multicentric trials in six centres in India to test impact of its double fortified salt and its acceptability and bioavailability. The study is expected to take 2–3 years.

The stability tests at University of Toronto (supported by MI/IDRC) are complete. Efficacy trials will be completed by June 1996. The main focus of these trials will be on biochemical impact and consumer acceptance.

Product: Rao (1990) reported that the bioavailability and stability of the double fortified salt under different conditions of storage and acceptability were found to be good. Mannar et al. (1989) reported that ferrous fumarate does not impart any noticeable colour to the salt and does not deteriorate with time in salt. Owing to the fine particle size (200 mesh), it can be added in a dry form as a rich mix and still get evenly dispersed in the salt. Its toxicity is less than that of ferrous sulphate and the effect on stomach lining is also less than ferrous sulphate or ferrous gluconate. A test report on iron and iodine levels in the double fortified salt estimated that 8 weeks after preparation there was no depletion.

Quality aspects: The purity of salt used for double fortification with iron and iodine is a critical factor to ensure the stability and bioavailability of the iron and iodine compounds. Presence of moisture in the salt hastens hydrolysis of the ferrous salts and imparts a brown colour to the salt. This also accelerates iodine losses. The presence of a high level of magnesium chloride in the salt increases its hygroscopicity (tendency to absorb moisture) and aggravates the problem.

Salt used for iron fortification will require a minimum purity of 99% (dry basis), a maximum moisture content of 0.5%, and a maximum magnesium level of 0.05%. The salt should be fine grained and of uniform size (0.5–1 mm).

Cost effectiveness: On the basis of prevailing prices in India (1990), the cost of machinery for a salt fortification unit producing 2 ton/hour has been estimated at US$40,000–US$300,000 depending on the extent of prerefining facilities required. The cost of processing fortified salt including the cost of chemicals and packaging are estimated at US$90/ton. Iron fortification adds 50%–200% to the cost of salt and costs US$0.30–US$0.65/head per year. The current price of ferrous fumarate and potassium iodide is US$8/kg and US$20/kg, respectively.

Observations: For the mutual coexistence of iron and iodine in double fortified salt, it was necessary to look for suitable stabilizers. Iron is stable in an acidic medium, whereas the iodine salt is alkaline. When mixed, oxidation of the iodide/iodate to free iodine takes place. The free iodine vaporizes and is lost. Alternatively, stable and neutral salts of iron had to be identified that are compatible with KI or KIO_3 in a slightly alkaline medium.

Future requirements/developments: The formulations need further testing for stability under a variety of environmental conditions. This will need to be followed by absorption tests in rats and humans to establish the efficacy of the product to control iodine and iron deficiency. The successful testing and large-scale application of available technology for the double fortification of salt would represent a major breakthrough for the global alleviation of the problems of iron and iodine deficiency.

FISH SAUCE

Country: Thailand.

Organizations and groups involved: Mahidol University and Ministry of Health, Bangkok, Thailand.

Target group: The Northeast Region of Thailand probably presents one of the most affected areas with respect to iron deficiency anemia because of, among other factors, the relative isolation of villages, extreme poverty, and poor living conditions. Iodine deficiency is common in Thailand. Prevalence surveys undertaken by the Nutrition Division, MOH, in 1992 found prevalence rates of goitre (grade 1a to 3) ranging from 1.42% to almost 40% of the population tested. Thirty-four of the 39 provinces tested had fallen into the WHO category of severely affected by iodine deficiency.

Vehicles: Although crystalline salt was the main source, the people also commonly ate salt in the form of "Nampla" (sauce extract from fish fermented in brine) and to a lesser extent "Plara" (a condiment extracted from fish fermented with salt, roasted rice, or rice bran).

Future requirements/developments: The formulations need further testing for stability under a variety of environmental conditions. This will need to be followed by absorption tests in animals and humans to establish the efficacy of the product to control iodine and iron deficiency.

DOUBLE FORTIFICATION WITH IRON AND VITAMIN A

RICE

Countries: Brazil, Japan, Philippines, Puerto Rico, Thailand, and the USA. Fortification of rice is an accepted practice in many countries but is legally enforced in only a few.

Organizations and groups involved: FDA, FNB-NRC, USDA, USAID, PHS (USA); FNRCC, FNRI; MOHW (Japan); Hoffman-La Roche; Merck Co.; Wright Enrichment Co.; RCL; Takeda Chemical Industries Ltd, Ajinimoto Company of Japan.

Vehicles: Rice is the staple diet of roughly one-third to one-half of the world's population. Out of the two edible whole grain forms, brown and white, there has been a worldwide trend to eat white rice in preference to the more nutritious brown. White rice is primarily a carbohydrate source, the bran layer has been removed during milling. White rice is mostly associated with the widespread occurrence of beriberi, caused by thiamin-deficiency. The loss of other vitamins and minerals, however, also has detrimental effects on human health. Undermilling, parboiling, acid-parboiling, conversion, and malekizing can prevent (some) nutrient loss, but such rice is less accepted. Enrichment is a logical step.

Fortificants: Rice is usually fortified with more than one nutrient. In the early days, only B-vitamins and iron were added. Later on, other nutrients like vitamin A were built in.

Virtually all iron salts are strongly coloured or darken rapidly by oxidation and hydration (particular under tropical conditions). Ferric sulphate gives the rice an off-white to yellow colour, which is undesirable to some customers. Reduced iron has the potential to turn rice grey to black. Because of its white colour, ferric orthophosphate or ferric pyrophosphate is most suitable for addition to rice but their bioavailability is arguable. When these ferric salts are oxidized or contain excessive moisture, they can turn tan, yellow, purple, and/or black. Their stability, however, is much better than ferrous sulphate.

Fortification with vitamin A is usually done with retinyl palmitate 250-SD, a stabilized vitamin A. Murphy et al. (1992) used initially pure retinol palmitate as vitamin A source, but its stability was not satisfactory. Retinyl palmitate was a better alternative.

Fortification level: In the US, many states followed the federal regulations of 1990 whereby each kg of enriched rice should contain 4.4–8.8 mg thiamin, 2.6–5.3 mg riboflavin, 35–70 mg niacin or niacinamide, 29–57 mg iron, 1,100–2,200 mg calcium, and 550–2,200 USP units of vitamin D. Calcium and vitamin D are optional, if added, the levels must agree with the federal regulations. Because of colour problems, riboflavin is often not added. There is no standard for brown rice.

In Thailand, 23,700 IU vitamin A/kg and 80 mg iron/kg are recommended in rice. Some rice fortification programs also use amino acids or proteins for fortification.

Table 8-1 shows fortification levels of vitamin A and iron in rice in several studies to illustrate the used levels.

Technology: process and equipment: Two types of enrichment are currently available – powder enrichment and grain enrichment.

Powder enrichment: To the rice a preblended powder mixture is added at a rate of 1:3,000–6,000. This type of rice should not be washed before cooking as most of the fortificants will be lost. Also, cooking in excess water will remove most of the fortificants. Powder enrichment is most effective when applied soon after milling and sifting. Because of the heat and moisture at the grain surface, the powder adheres to the grain well at this point.

The method of mixing nutrients at the time of cooking has the same principle. A mixture of nutrients (powdered or in tablets) should be dissolved in the cooking water. The water must be absorbed totally by the rice. This method is only suitable for mass cooking.

Grain enrichment: This type of enrichment is known as premix and is the most common way to fortify rice. It consists of grains of rice that have been treated with vitamins and minerals that will not rinse off the rice when washed. Usually, the grains are highly concentrated and must be blended with ordinary white rice, mostly at a rate of 1:200. Several methods have been developed over the last 50 years. The most simple method of grain enrichment is to apply a concentrated powder blend to milled rice and then coat the rice with a water-insoluble, food-grade material that cannot be rinsed off.

The first patented method in the US (1940s), was the *Hoffman-La Roche method.* For this, a premix (a sulphuric acid solution of thiamin hydrochloride and nicotinamide) is sprayed onto the surface of tumbling white rice contained in a horizontal rotating drum or trumbol. Rice is dried, assisted by hot air. A protective coating (an ethanol or isopropanol solution of zein, fatty acid (palmitic or stearic acid), and abietic acid) is applied, immediately followed by an application of talc and ferric orthophosphate powder. After drying, the latter process is repeated until the required iron level is reached. The finished product is sieved, packaged, and distributed for blending. Addition to

Table 8-1. Levels of iron and vitamin A in unfortified and blended fortified rice.

Rice	Iron (mg/kg)	Vitamin A (IU/kg)	Reference
White rice	6.6–8.8	–	Furter et al. (1946)
White rice	5	–	Hunnell et al. (1985)
Brown rice	15–18	–	Furter et al. (1946)
Brown rice	11	–	Hunnell et al. (1985)
Coated (Hoffman-La Roche)	28	–	Furter et al. (1946)
Coated based on Hoffman-La Roche	55	13,200	Cort et al. (1976)
Coated based on Wright	88	16,000	Cort et al. (1976)
Coated (RCL-method)	20	–	Bramall (1986)
Coated	–	9,250	Rubin et al. (1977)
Coated	6	2,400	Peil et al. (1981)
Infused (Japanese Shingen)	11	–	Hunnell et al. (1985)
Artificial rice grains	–	12,500	Murphy et al. (1992)
Artificial rice grains	20	4,075	Gershoff et al. (1977)

plain white rice occurs at the rate of 1:200 (Furter et al. 1946). This method has improved during the years but it is still a basic method used today for rice fortification.

The *Merck Co. method*, patented in 1955, is the other main basic method used. The same sort of rice premix concentrate is manufactured with an acetone/water suspension of thiamin hydrochloride, nicotinamide, an iron salt, and ethyl cellulose. When this coating dries, several coats of an alcoholic shellac solution containing a whitening agent are applied to yield a glossy white grain. Again blending has to be done at a rate of 1:200 with untreated white rice.

The *Wright Enrichment Co. method* produces a fortified rice premix using a process based on a combination of the Hoffman-La Roche and the Merck Co. process.

In 1981, a new, simpler method was developed by *Ricegrowers' Co-operative Limited* as an answer to the less-accepted Hoffman-La Roche rice premix (*RCL-method).* A surface adhesive technique has to be used and discoloration has to be prevented by using ferric orthophosphate. An acid was used to dissolve iron, thiamin, and niacin. This solution does not react with the iron salt and, therefore, prevents the colour change. It generates a thin, sticky sugar layer by reaction with the surface starch of the rice particles. The ferric orthophosphate is bound to the rice in the sugar coating. After applying the solution to the rice (in trumbol), it is dried and the premix is ready for blending (Bramall 1986).

In Japan, for many years mostly thiamin/riboflavin enriched rice was eaten. Since 1981, multinutrient enriched rice has been marketed in Japan. It is called *Shingen*, which means "brown rice in the new age." The rice is manufactured using infusion by a combination of acid-parboiling before coating. Polished rice, therefore, is soaked in a 1% acetic acid solution containing water soluble vitamins (thiamin, riboflavin, niacin, pantothenic, acid and pyridoxine). The soaked rice is then steamed, dried, and coated with vitamin E, calcium, and iron separately in different layers. Finally, a protective coating material is applied to prevent losses through washing. The coating melts at 70°C, but is insoluble in cold water (In Japan, the usual cooking method is with total water absorption.) It is different from the coating of Furter et al. (1946). The premix is packed under CO_2 (to prevent vitamin E destruction) and ready for blending in a rate of 1:200 (Hunell et al. 1985; Misaki and Yasumatsu n.d.).

Liuzzo et al. (1992) claim to have a more stable premix with their *cross-linked grains*. The rice is incubated with an aqueous vitamin (thiamin, riboflavin, niacin, and pyridoxine)-solution at pH 2.3–2.5 for 30 minutes, then acetaldehyde (the cross-linking agent) is added and incubation at 60°C for 45 minutes follows. After washing with tap water and neutralizing with ascorbic acid, the grains were air-dried to a moisture content of 10–14%.

An even more stable premix was claimed by Peil et al. (1981). They found a coating that is *more resistant against cooking in excess water* than others and soluble at 37°C. The best they found was made by 1.2% (w/w) methylcellulose A 15, 3.6% hydroxypropyl methylcellulose F50, 28.5% ethanol (95%), and 66.7% water. This polymer solution is sprayed on rice and dried in six layers:

1. 0.8 mg thiamin and 6.66 mg niacin/g polymer solution,
2. 7.3 mg riboflavin/g polymer solution,
3. Reduced iron powder was sprayed alternately with polymer solution in a rate of 37 mg/g polymer solution,
4. A layer of unfortified polymer solution to separate,
5. Vitamin A (250-SD) was sprayed alternately with polymer solution in a rate of 455 IU/g polymer solution, and
6. A layer of unfortified polymer solution to seal the coating.

A totally different basic method of the grain type of enrichment is the manufacturing of *artificial rice*. Attempts are made here to manufacture enriched artificial rice (simulated rice kernels) that is mixed with regularly milled rice. The cooked rice containing the artificial rice often had a poor appearance. By now, it is possible to make acceptable grains of a dough of fortificants and a binder of starch (e.g., rice flour) or proteins, using an extrusion process. Temperatures of 100–200°C are used. Also, a coating is often added to prevent losses through washing. Usually, heat-labile vitamins as vitamin A and thiamin are sprayed on the artificial rice because of the high temperature during the extrusion process.

Status and results of field trials: Most of the rice sold in the US is enriched, fortified rice is normally available in Japan and Puerto Rico.

Field trials in the Bataan province of the Philippines, which provided fortified rice according to Furter et al. (1946), reported 76–94% decrease in the incidence of beriberi within a few years (Salcedo et al. 1950). Also, some Japanese studies reported positive effects of rice fortification programs. Increased thiamine blood levels and numbers of red blood cells with subjects fed with multinutrient fortified rice were observed. Misaki and Yasumatsu (n.d.) and Gershoff et al. (1977) could not find an improvement of general health during a 4-year feeding program in Thailand with rice fortified with vitamin A, iron, thiamin, and amino acids. The investigators were unable to explain the results obtained.

Quality aspects: A fortified rice premix should look like rice, cook like rice, taste like rice, and maintain its nutrient qualities through rinsing and cooking. If the premix grains look different, they will be picked out by the consumers. That is why riboflavin is often not added, it forms bright yellow spots in the cooked rice. It is possible to hide the colour in grains fortified with riboflavin, but it still forms the yellow colour during

cooking, which is not acceptable to many consumers. In Japan, the yellow colour of the rice premix has been accepted since the 1950s. Talc is also used to obtain the right, white colour.

Consumer habits have a significant influence on the availability of the nutrients in the meal. For example, whether the rice is rinsed before cooking and whether it is cooked with a measured amount of water, which is completely absorbed, or with excess water, which is drained off and thrown away.

In the US, the standard requires that the label on enriched rice includes the statement: "To retain vitamins, do not rinse before or drain after cooking." The statement is not required if >85% of the minimum levels remain after cooking by a prescribed method. In South Asia, it is common practice to cook rice in excess water. The Philippine Food and Nutrition Institute (FNRI) judged a washing loss of vitamin A of 10–20% as unacceptable. Fifty-percent cooking stability is the minimum.

Cost and cost effectiveness: Powder enrichment is less expensive than other forms. Coating is slightly more expensive. According to Yong (1979) prices for total enriched rice (including amino acids) would be US$0.078, 0.080, and 0.073 per kg fortified rice for a surface coating method, an infusion method, and artificial rice, respectively. One reason to develop the RCL-method was that the Hoffman-La Roche production took too much time. Because of the simplicity of this method it is much cheaper.

Observations:

Storage stability: The minerals and vitamins in powder-enriched rice are less stable and they can easily react with other food compounds. The most-used rice fortification methods seems to be adequate for storage. The RCL premix (containing thiamin, niacin, ferric orthophosphate) showed no significant colour change and no loss of nutritional quality after 12 months under tropical storage conditions. It was developed because the Hoffman-La Roche rice was found to be easily distinguished from plain white rice, and it rapidly darkened in colour under tropical storage conditions.

An exception has to be made for vitamin A. Stabilization is the main problem with the fortification process (Hoffpauer 1992). Cort et al. (1976) made fortified rice based on the Hoffman-La Roche method and on the Wright method. The Hoffman-La Roche method showed storage losses of 12% vitamin A, whereas the Wright method only showed 1% loss. Rubin et al. (1977) found a 13% loss of vitamin A and no loss of iron during storage of rice premix based on Hoffman-La Roche. Vitamin A in artificial rice grains according to Gershoff et al. (1975) had lost 50% of its activity during processing and storage.

Murphy et al. (1992) found a vitamin A half-life of 238–408 days in artificial grains (at T=25°C, a_w=0.11). Storage stability was affected by the presence of several antioxidants and oils. If no ascorbate is present, an increased humidity is detrimental. In a humid atmosphere, however, artificial rice usually clumps together when stored. Combinations of more saturated oils, tocopherol, and ascorbate are recommended for adequate preservation of vitamin A in the artificial rice grains, particularly in tropical environments. Unfortunately, there was no correlation between storage stability and cooking retention.

Retention after washing: Ordinary white rice lose about 60% of its iron (and vitamins) through washing because what is left after milling is usually close to the surface (Furter et al. 1946). If powder enrichment is used, 20–100% of the enrichment will wash off the rice.

Because most consumers insist on washing rice before cooking, it is important that any method of enrichment of white rice protect the added nutrients against washing. Today, coating methods seem to be adequate, although Murphy et al. (1992) found washing losses of 10–20% with vitamin A fortified rice enriched by Wright Enrichment, Inc. Rubin et al. (1977), however, found washing losses of only 1.1% of vitamin A and none of iron with fortified rice based on the Hoffman-La Roche method. Artificial rice used by Murphy et al. (1992) showed no loss of vitamin A through washing. The cross-linked method (Liuzzo et al. 1992) claims to have less loss during rinsing, cooking, or processing, but they did not fortify with iron or vitamin A.

Retention after cooking: Cooking losses can be very little if rice is cooked in a suitable amount of water that can be absorbed totally. Cort et al. (1976) made fortified rice based on the Hoffman-La Roche method and on the Wright method, adding thiamin, pyridoxine, niacin, vitamin E, vitamin A, folic acid, iron, calcium, zinc, and talc. Cooking losses in both methods were only 1%. Stability of vitamin A rice that was cooked was strongly decreased, even on cooling temperatures. That agrees with the results of Murphy et al. (1992) who reported a detrimental effect on vitamin A stability under more humid storage conditions. The artificial rice grains of Murphy et al. (1992) showed vitamin A cooking retention of 55–96%, affected by the presence of several antioxidants and oils. Cooking in excess water resulted in 81% loss of vitamin A of the fortified rice based on the Hoffman-La Roche method (Rubin et al. 1977). Peil et al. (1981) improved the coating, and they managed to lose only 30% vitamin A.

Bioavailability: As described in Chapter 7 (Single Fortification of Iron in Wheat Flour and Bread), the presence of ascorbic acid has an enhancing effect on iron absorption, not only in bread but also if iron is eaten with rice. The presence of rice itself in the diet inhibits iron absorption, as most vehicles do. Addition of ascorbic acid to fortified rice may be an improvement to be considered. If the ascorbic acid is oxidized during long or excessive heating of the food, this effect is reduced. This might occur during rice cooking (Sayers et al. 1974; Guiro et al. 1991). Incorporation of glucose in the rice diet seems to have an inhibiting effect on iron absorption. Incorporation of starch or lactose seems to have the

least inhibiting effect, whereas sucrose or fructose were in between (Snehalata and Reddy 1985).

SUGAR

An approach to control iron deficiency and vitamin A deficiency where dietary availability of the two micronutrients is low is to fortify a vehicle consumed by all the deficient populations. This has been tested in a double-blind field study in four highlands and lowlands, semirural, low-income communities in Guatemala (Viteri et al. 1995).

Countries: Guatemala.

Organizations and groups involved: INCAP, University of California, Berkeley; PAHO/WHO; Kellogg's Latin America; USAID.

Vehicles: Sugar has already been shown to be an adequate vehicle for vitamin A fortification in Guatemala, and it does not impair iron absorption (Layrisse et al. 1976).

Fortificants: In this field research, sugar was doubly fortified with retinyl palmitate and FeNaEDTA.

Fortification level: One gram FeNaEDTA/kg sugar, providing 130 mg Fe/kg sugar and 15 mg vitamin A/kg sugar. Twelve sugar samples were obtained sequentially at the packaging site, covering the production period of each of five sugar batches produced for the study.

Technology: Process: FeNaEDTA was added by a sugar factory in the lowlands of Guatemala to the vitamin A-fortified sugar already being produced by the factory. This addition, as described by Viteri et al. (1995), was achieved by manually delivering, in a sweeping motion, the yellow powder to the last centrifugation of refined sugar while it still had about 2% humidity. The amount was added to the sugar load that each centrifuge delivered. The sugar discharged by each centrifuge fell into a conveying screw that carried and mixed the sugar to its final drying and further mixing stage before packaging. This process did not alter the normal flow of sugar production.

Status and results of field trials: Iron stores in the fortified communities increased significantly except for women 18–48 years of age in one lowland community. Iron stores in the control community remained unchanged except for a rise in adult males. It is highly improbable that this is caused by a possible effect of vitamin A fortification of sugar, which has been consumed in this and all other communities for several years.

Quality aspects: The doubly fortified sugar was very stable except for a slow progression of brownish discoloration in extreme conditions that was noticeable after 6 months of storage under the most severe environmental conditions. No settling of NaFeEDTA or vitamin A to the bottom of the sacks stored under natural storage conditions in tropical, humid environments was noted. Acceptability and organoleptic properties of commonly used food recipes were completely satisfactory. A qualitative test to detect iron in sugar was also introduced to reinforce the exchange of unfortified sugar for the fortified one when the former was occasionally filtered into the fortified communities.

Cost: Cost–benefit analysis of sugar fortified with iron and vitamin A proved to be extremely favourable.

Observations: A systematic monitoring of compliance and of changes in nutritional status should be established. This should include serum ferritin determinations in well-defined samples of adult males to prevent any long- term risk of iron overload, although, currently, this is a very remote possibility.

BLENDED/FORMULATED FOODS

Blended/formulated foods are made by blending several component ingredients to produce a food that is nutritionally improved compared to any of the individual components. The formula usually contains a staple cereal (like wheat, rice, corn, groundnut, sorghum) and a high-quality protein source such a soybean, milk powder, whey, and the like.

Many different varieties have been developed around the world. Examples of infant foods from Ethiopia, Nigeria, India, and Tanzania are described in Table 8-2. There are many more examples, however, of double-fortified infant foods in many other countries. The ingredients may be milled or undergo

Table 8-2. Nutritional value per 100 g product.

Infant formula Nutritional value	*Faffa (Ethiopia)*	*Balahar (India)*	*MPF (India)*	*Soy-Ogi (Nigeria)*	*Lisha (Tanzania)*
Energy	1,400 KJ	1,700 KJ	1,600 KJ	1,700 KJ	1,500 KJ
Protein	21.0 g	15.0 g	42.0 g	20.0 g	18.0 g
Protein-energy-%	25.0%	14.8%	44.0%	20.0%	20.0%
Fat-energy-%	6.0%	27.0%	20.0%	14.0%	19.0%
Iron	15.0 mg	–	–	–	–
Vitamin A	–[a]	3,000 IU	3,000 IU	1,430 IU	–

[a] = Depending on added vitamin/mineral mix.
Source: Caritas Neerlandica (1983).

some sort of further processing (heating, parboiling, rolling, extruding, etc.). Nutritional value is enhanced by fortification of blended foods with minerals and vitamins and, to increase their acceptability, sugar is usually added to the formula. These foods may be cooked and served as a meal or made into a drink and they can be used to supplement another less nutritious food, e.g., cassava (Barrett and Ranum 1985).

Countries: Ethiopia (Faffa), India (Balahar, multi purpose food), Nigeria (Soy-Ogi), Tanzania (Lisha).

Organizations and groups involved: ENI (Ethiopia), CFTRI (India), FIIRO (Nigeria), TFNC (Tanzania), WFP.

Target group: Infants and pregnant and lactating women.

Vehicles: Infant foods consist of a cereal (wheat, maize), a high-quality protein compound (soybean, chickpea, DSM), and a fat component (groundnut, soybean).

Fortificants: Vitamin A and iron (see Table 8-3).

Technology: Process: The chickpeas in ***Faffa*** are precooked before milling to increase digestibility.

Soy-Ogi: Maize and soybeans are selected and washed. Maize is soaked overnight and wet-milled into a slurry. Soybeans are heated, dehulled, cooked (10 minutes), and wet-milled into a slurry. The maize, soybeans, and minerals are mixed and pasteurized. It is spray dried and the powder is mixed with a vitamin/mineral premix.

Lisha: A mixture of maize and soybeans is made into a thick paste by a low-cost extrusion cooker, the pulp is dried and milled. The powder is mixed with milkpowder and the vitamin/mineral premix.

Status: Full production.

Product: The composition of the various infant foods are shown in Table 8-3. Vitamins and minerals are added for fortification and sugar for flavouring. Local ingredients are used (see also Chapter 7).

Quality aspects: *Soy-Ogi* is kept for 3–6 months in polyethylene bags, packed in carton boxes, or kept 9–12 months in tins. The keeping quality of groundnuts used for Balahar is a major problem because of aflatoxin contamination. For the other products, the keeping quality is not mentioned and generally is not a primary concern.

Marketing/distribution channels:

Faffa was originally distributed through retail trade in the 1960s–70s. Then, for a few years, it was mainly used for emergency relief. In the 1980s, commercial sales increased again. Production now is taken over by a government company.

Balahar: Almost all production is distributed through supplementary feeding programs. In 1976, a production of 40,000 tons was mentioned. Commercial marketing never succeeded.

MPF was used almost solely in supplementary feeding programs. Product promotion was neglected and the product has never reached retail shops.

Soy-Ogi: Distribution is done through the government and retail shops. The production in 1980 was 17 tons.

Lisha: Commercially marketed.

Cost and cost effectiveness:

Faffa: The cost was US$0.90/kg (1982). Sold at a subsidized price of US$0.50/kg.

Balahar: Little is known about the actual price. A cost price of US$0.40/kg was mentioned in 1965.

MPF: Actual prices are not known. A cost price of US$0.33–0.72, depending on packaging material, was mentioned in 1972.

Soy-Ogi: Production cost was US$1.70/kg and wholesale price was US$2.18 (1982).

Lisha: Retail price was US$1.96/kg (1980).

Table 8-3. Composition of some infant foods.

	Faffa	*Balahar*	*MPF*	*Soy-Ogi*	*Lisha*
Wheat flour	57%	65%	–	–	–
Soya flour	18%	–	–	30%	–
Groundnut flour	–	25%	–	–	–
Chickpeas	10%	10%	25%	–	–
Maize flour	–	–	–	70%	–
Maize grits	–	–	–	–	65%
Hulled Soybean	–	–	–	–	28%
DSM	5%	–	–	–	5%
Sugar	8%	–	–	–	–
Salt	1%	–	–	–	–
Vitamin A + iron	1%	<1%	<1%	<1%	1%
Defatted peanut	–	–	75%	–	–

Source: Caritas Neerlandica (1983).

Project/program evaluation:

Faffa was marketed in 1967 for the first time. In 1969, the composition was changed as a result of market plus acceptability studies. It is better accepted by women with higher education and families with a steady income. Market studies (1982) showed that 75% of the users were from low-income groups.

Balahar was developed to replace CSM. No market or acceptability studies preceded the introduction. A large proportion of the target group (preschool children) was not reached.

MPF had been tested in 300 institutions on acceptability and use before production started in 1960. MPF has never reached retail shops, and the use in supplementary feeding programs has decreased because of imported free donations of other foods.

Soy-Ogi market surveys showed good acceptance and a high demand for Soy-Ogi.

Lisha product development was preceded by a series of surveys on traditional weaning food practices and recipes. Initial mixtures of maize with beans, fish, or meat were tested but the products were too expensive. Soybean proved to be the best accepted legume that has been tried.

MAIZE

Countries: Some African countries, Canada, Chile, Guatemala, South Africa, the US.

Organizations and groups involved: FDA, NAS/NRC, USDA/CSRS, USDA/ARS, IAEA, SAAEB, SASA, WT, UNU, and Hoffman-La Roche Inc.

Vehicles: Maize grits, fine and course maize, degerminated and soya have been used for fortification.

Fortificants: Maize meal and commercial grits are fairly similar to wheat flour in moisture content and are normally sufficiently shelf stable. Multiple fortification is often performed in a similar fashion to fortification of wheat flour and bread. For the enrichment of maize meals and grits, however, elemental iron powder is the preferred iron source because soluble reactive iron salts such as ferrous sulphate are prone to rancidity.

Even stabilized ferrous sulphate, the so called bio-iron, causes rancidity sooner than elemental iron. The latter does not cause functional problems of separation, colour, or rancidity. Ferric phosphate or ferric sodium pyrophosphate could also be used without functional problems, but their bioavailability is less than that of reduced iron (Anderson 1985). Just like wheat flour, fortification with vitamin A is usually performed with retinyl palmitate, a stabilized form of vitamin A.

Fortification level: The original iron levels in maize are 24 mg/kg whole meal unbolted, 18 mg/kg bolted meal, 11 mg/kg degerminated meal, and 10 mg/kg maize grits. The FDA standards for enrichment are 28–57 mg iron/kg for maize meal and flour, 46–57 mg/kg for grits, and none for whole corn meal, which does not have an enrichment standard (Ranum and Loewe 1978).

Maize does contain vitamin A activity that is present naturally, whereas other cereals do not. The recommended level of fortification with vitamin A in maize meal and related products in the US is 22,000–26,000 IU/kg, but this is not a federal standard. In most studies, the added amount of vitamin A is lower (11,000–16,000 IU/kg, due to older recommendations (Cort et al. 1976; Rubin et al. 1977; Yong 1979; Parrish et al. 1980a).

Technology: Process and equipment: When the maize is milled and consumed without rinsing or discarding the cooking water, it can be fortified in the same ways as wheat.

For wet-milled maize, there is no need to sift the product into particle sizes. It can be fortified simply by adding a fortification mixture by hand or with a feeder. Powdered premix, therefore, is sufficient and there is no need for palletization of the premix. The more humid conditions, however, might affect the stability of vitamin A, which is particularly unstable in such circumstances.

Maize grits present more fortification problems than wet milled maize-dough because they are often rinsed before cooking. Technologies like those for fortifying milled rice may be suitable (Yong 1979).

For tortillas, maize is cooked in water with limestone and washed to remove the outer hull before grinding. The iron content of the dough is affected by the grinding process – the grinding stones used in the villages of Guatemala increase the iron content in dough compared to dough made by hand or by motorized mills. Other circumstances did not affect the iron level (Krause et al. 1993).

Status and results of field trials: In the US, most of the maize meals and commercial grits are enriched, usually with reduced iron. Because vitamin A is not included in federal regulations, fortification of corn products with vitamin A is not common in commercial products. In studies, it is often added as an extension of bread fortification studies.

Observations:

Bioavailability: The bioavailability of iron in maize products is not totally similar to that in bread because processing has a great influence on availability. Absorption of nonhaeme iron is still low; Derham et al. (1977) report 3.8% absorption of ferrous sulphate from maize-meal porridge. Morón et al. (1989) studied extruded maize–soybean fortified with iron, vitamin A and others. Iron absorption (ferrous fumarate) varied between 2.4% and 6.8%.

Inhibiting/enhancement: Derham et al. (1977) reported the inhibitory effect of tannin in tea, mentioned earlier in Chapter 7 (Single Fortification with Iron in Wheat Flour and

Bread). A strong enhancing effect of ascorbic acid is seen in maize meal porridge by Derham et al. (1977) and Sayers et al. (1973). The processing temperatures were low enough to prevent oxidation of the ascorbic acid (as is seen in bread), to avoid depressing its enhancing effect.

Storage: Stability of vitamin A in milled maize (meal and grits) at room temperature is not as good as in wheat flour. Losses were up to 20% in 6 months, but the moisture content was an important factor. A 6.5% moisture content showed hardly any loss, whereas 11.4% in maize grits lost one-fifth of vitamin A. Also at higher storage temperatures, vitamin A losses increase – up to 40% loss in 3 months at 45°C. These values do not really differ from results found in wheat flour. A 15% average vitamin A in milled corn will provide for storage losses at warehouse conditions (Cort et al. 1976; Rubin et al. 1977; Parrish et al. 1980a).

Iron added as reduced iron was found to be stable at both temperatures in all milled maize. When stabilized ferrous sulphate is used, deterioration occurred. If iron levels increased (from 88 to 440 mg/kg) off-flavours showed up with all iron sources. In soya-fortified maize, stabilized ferrous sulphate was found to be an acceptable iron source for fortification. Segregation of iron sources in milled maize was not noted (Anderson et al. 1976; Rubin et al. 1977; Anderson 1985).

Processing retention: Processing the maize meal or grits causes losses of vitamin A – the longer the cooking temperature the greater the loss. Losses up to 30% with 30 minutes cooking were reported. Making maize bread causes the usual processing loss, but storage stability is little less than in wheat flour bread (Rubin et al. 1977; Parrish et al. 1980b).

WEANING RUSK

Countries: China.

Organizations and groups involved: Institute of Nutrition and Food Hygiene, Academy of Preventive Medicine, (China); MRC Dunn Nutrition Centre, Dept of Trade and Industry, United Biscuits, and APV Baker (UK).

Target group: Weanling children.

Vehicle: Rusk made from wheat flour, sugar, and vegetable oil.

Fortificants: Vitamin A and iron as ferric ammonium citrate. The latter proved to be much more palatable and acceptable than cheaper iron salts.

Technology: The micronutrient components were prepared as a premix, before being used for rusk manufacturing.

Status and results of field trials: During the field trial, palatability and compliance appeared to be good. Despite the plant acids in the flour, the rusk was shown to be an effective and, thus, an available source of iron. The iron added to the rusk is likely to be bioavailable.

Fortification level: See Table 8-4.

Product: The rusk is a biscuit product that has low residual moisture and is rapidly soluble in warm liquids.

Quality aspects: The advantage of the rusk weaning food is the long shelf life.

Cost and cost effectiveness: The cost of production was 1.4 renminbi (yuan)/100 g, which seems to be reasonable. On the assumption that one rusk would be eaten every day, a typical rural family would spend 4% of its income on the rusk.

Observations: The rusk (one per child per day) was eaten either dry or taken in liquid form, after dispersion in water. Some evidence of interaction between iron and vitamin E was shown. It was stated that other antioxidant micronutrients, like

Table 8-4. Nutrient content of fortified rusk.

Nutrients	*Per gram*	*Per rusk (17 g)*	*Chinese RDA[a]*
Protein	60.0 mg	1.0 g	2–4 g
Fat	80.0 mg	1.4 g	–
Sugar	310.0 mg	5.3 g	–
Energy	9.2 KJ	156.0 KJ	–
Vitamin A	13.2 µg	224.0 µg	200.0 µg
Iron	0.29 mg	5.0 mg	10.0 mg
Calcium	17.6 mg	300.0 mg	600.0 mg
Zinc	180.0 µg	3.0 mg	5.0 mg
Cholecalciferol	0.22 µg	4.0 µg	10.0 µg
Thiamine	0.009 µg	0.15 µg	10.0 µg
Riboflavin	12.0 µg	200.0 µg	400.0 µg
Niacin	147.0 µg	2.5 mg	4.0 mg
Cyanocobalamin	0.018 µg	0.3 µg	
Folic acid	1.47 µg	25.0 µg	

[a]Per kg body weight.

vitamin C and carotenoids, could not be included because of their instability during baking. The composition of the premix could be varied to make it suitable for different regions.

Future requirements/developments: The optimum composition of the supplement may require further study. Inclusion of vitamin E as a protective substance and heat-stable antioxidant needs to be considered.

OTHER VEHICLES, e.g., MONOSODIUM GLUTAMATE (MSG)

Countries: Philippines.

Organizations and groups involved: Ministry of Health, Philippines; Hoffman-La Roche, USA.

Target group: See Chapter 7 "Milk and Milkpowder."

Fortificants: The preferred source of iron to be added to MSG should have good bioavailability, have a bland taste, and be nearly white in colour. It should be low in cost and available commercially.

Micronized ferric orthophosphate (produced by Joseph Turner Co.) and zinc stearate-coated ferrous sulphate (produced by Durkee's Industrial Foods Group) have been added to MSG along with stabilized vitamin A palmitate type 250-SD. Durkees-coated ferrous sulphate is a light-coloured, tasteless, relatively nonreactive, free-flowing powder varying in particle size (100–200 mesh). The coating protects the ferrous sulphate up to a temperature of 122°C, the melting point of the encapsulating material. For characteristics of ferric orthophosphate, see Chapter 7.

Fortification level: Sachets comprising 2.4 g fortified MSG contained 15,000 IU vitamin A and 50 mg iron.

Technology: Process and equipment: See Chapter 7, "Milk and Milkpowder."

Status and results of field trials: Laboratory.

Quality aspects: Products were found to have favourable colour, taste, bioavailability, and particle size characteristics. Storage trials indicated that the iron did not influence vitamin A activity.

Future requirements/developments: Large-scale production trials and field testing need to be carried out.

MULTIPLE FORTIFICATION WITH IODINE, IRON, AND VITAMIN A

CEREAL BASED FLOUR

Countries: USA.

Organizations and groups involved: CSRS (Parrish et al. 1978); FNB-NRC.

Target group: All American society.

Vehicles: Wheat flour, semolina (from durum), maize flour, maize meal.

Fortificants: Vitamin A was added as retinol palmitate or dry retinyl palmitate. For total fortification of the flour, iron (as ferrous sulphate and electrolytically reduced iron) and other vitamins and minerals were also added.

Fortification level: In 1974, the Food and Nutrition Board of the National Research Council/USA proposed a new fortification for cereal grain products. The added vitamin A level was 5,000 IU/pound flour, which is 15% coverage of the NAS fortification level of 4333 IU/pound (= 1.3 retinol equivalents).

Technology: Process and equipment: The carrier for the vitamin-iron premix was maize starch, about 40% of the premix weight. Vitamin and mineral enrichment materials were premixed with 5 pounds of flour by "fluidizing" (shaking) in a closed plastic bag filled with air. Flours were mixed in 100- or 200-pound lots in a Wenger double-ribbon horizontal batch mixer. Equally divided portions of the premix were distributed on the top of each 50 pounds of flour after it was spread out in the mixer. Flour and premix were blended for 15 minutes (Parrish et al. 1980).

It is also possible to add fortification materials during flour making in a production mill. Parrish et al. (1980) used a Sterwin enrichment feeder and found no differences in vitamin A content compared to the mixing method.

Status and results of field trials: Laboratory scale.

Stability of vitamin A: Losses of vitamin A during storage of flours (made of wheat and durum) were up to 10% in 6 months at cooling and room temperature (i.e., 3°C and 21–32°C). Losses in maize flour and meal were a little more: over 20%. An average of 15% of the proposed levels might be more than needed under normal conditions. Storage at 40°C showed losses of about 50% in all flours. This is confirmed by other workers; the loss stabilizes probably after 3 months. Yellow maize contains natural carotenoids with provitamin A activity. Their loss during storage tests was about twice that of stabilized vitamin A (Parrish et al. 1978, 1980). The bioactivity of the remaining vitamin A did not change during storage (Liu and Parrish 1979). No losses were reported during pneumatic conveying or simulated shipping and handling (Parrish et al. 1980).

INFANT FOODS/FORMULAS

Project title: New approach to low-cost weaning food production.

In 1986, the Royal Tropical Institute (KIT) presented the blueprint for a "new approach to low-cost weaning food production" (KIT 1987). This approach was developed in a research project on low-cost weaning food production carried out in cooperation with the CHNO in Benin (Altes and Merx 1985). In this approach, emphasis is given to the self-sustaining character and the gradual expansion possibilities of planned activities. Since its introduction, 22 production units

have been implemented in 13 projects in 12 different countries in Africa, Asia, and Latin America. These projects have shown that a low-investment, labour-intensive project for manufacturing weaning foods on a semi-industrial scale from indigenous raw materials can be successful (Dijkhuizen 1992).

Countries, organizations, and parties involved: Projects were carried out under the auspices of the Netherlands government (Benin, Burundi, Mozambique, Niger), EC (Sierra Leone), Caritas Neerlandica (Dominican Republic, Ghana, Jamaica), NOVIB (Ghana), and WFP (Bangladesh, Kenya, Malawi, Nepal). Also see Table 8-5.

Target group: Infants and pregnant and lactating women.

Vehicles: The infant food is generally composed of 80% cereals (wheat, rice, maize, sorghum), 10% pulses (soybean, cowpea, mungbean), and 10% oilseeds (groundnut, sesame seed). Vitamins and minerals can be added for fortification and sugar for flavouring. Local ingredients are used. The result is a nutritionally improved formula compared to any of the single ingredients. See also chapters 7 and this chapter under "Infant Foods/Formulas."

Fortificants: Although addition of micronutrients in most cases was not considered, there are no technological constraints for multiple fortification of these weaning foods.

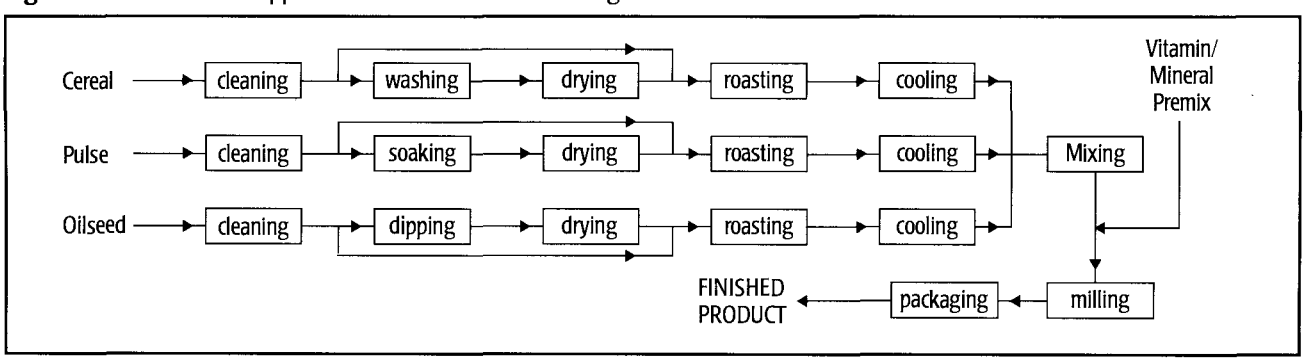
Technology: Process and equipment: Cereals and pulses are cleaned by means of a mechanical winnower and/or by hand. If needed, the cereals are washed with clean water and dried. Pulses like soybean may undergo a special soaking/steaming treatment to inactivate the antitrypsine enzyme and prevent flatulence. Groundnuts are selected manually and may undergo a special treatment (dipping in boiling, salted water and drying) to remove the mould infested groundnuts that discolour after this treatment. The roasting is done in either a scorcher, electric oven, or rotating drum. After cooling, the ingredients are mixed, milled in a hammermill, and packed. See Figure 8.1 for a flow chart of the KIT approach in infant food manufacturing.

Table 8-5. Countries and parties involved in infant food production.

Country	*Product name*	*No. of units and annual capacity (ton)*	*Technical assistance*	*Year of implementation*
Africa				
Benin	Farine Bébé	1/100	KIT/DGIS	1979 –
Burundi	Musalac	6/800	KIT/DGIS	1985 –
Ghana	Vitalmix	1/100	KIT/NOVIB	1987 –
	Nutrimix	1/25–75	KIT/Caritas	1987 –
Kenya	U-mix	2/1,000	KIT/WFP	1992 –
Malawi	Likundi Phala	4/600–800	KIT/WFP	1991 –
Mozambique	Farina Lactea	1/500–1,000	KIT/DGIS	1993 –
Niger	Bitamin	1/30–100	KIT/DGIS	1990 –
Sierra Leone	Bennimix	1/250–250	KIT/EC	1989 –
Asia				
Bangladesh	Unknown	1/250	KIT/WFP	1994 –
Nepal	Unknown	1/250	KIT/WFP	1993 –
Latin America				
Dom.Republic	Prosur	1/30–100	KIT/Caritas	1990 –
Jamaica	Unknown	1/500–1000	KIT/Caritas	1993 –

Note: KIT = Royal Tropical Institute, DGIS = Dutch Directorate General International, NOVIB = Netherlands Organization for International Development Cooperation, WPF = World Food Programme, EC = European Community.

Fig. 8-1. Flow chart "KIT approach" infant food manufacturing.



Status and results of field trials: Full production. Good acceptability of the products.

Product: The product is used as a porridge. Boiling with water for about 15 minutes is necessary to get a smooth porridge. On adding cold water, lumps will be formed since it is not an instant product.

Quality aspects: The product has a nutritional composition of 400 Kcal/100 g, 13% protein, and 7% fat. The product quality is excellent.

Tests have shown that the product is microbiologically safe. Depending on the type of packaging material and storage conditions the shelf life of the flour is 2 weeks to more than 4 months (in polyethylene and aluminium laminate foil, respectively).

Marketing/distribution channels: The infant foods are either distributed by feeding program or by sale on the open market. In Burundi, e.g., marketing is done by women vendors who earn commissions and are obliged to provide nutrition education.

Cost and cost effectiveness: An average 100-ton project has an annual turnover of US$60,000 with a required investment of US$ 60,000. The rate of return is 10–20%. The price is half or less the price of imported weaning foods.

Project/program evaluation: Over the past few years, the low-cost weaning food projects have proven their economic value. The Musalac project was awarded the WHO annual prize in 1989 for the most innovative primary health care project.

Observations: The advantage of this product compared to the imported instant products is not only price but also the necessity to cook the flour to make it consumable. Often the projects are attached to a hospital or health centre. The Musalac project is supported by the Netherlands government to operate as a training centre for low-cost food production in Africa.

PROCESSED BEVERAGES

Countries: Mexico (Tanzania and Philippines are testing new products) and the US.

Producer: Various companies in the USA. Procter and Gamble Co., Cincinnati, Ohio, USA has been involved in producing fortified beverages for Mexico, the Philippines, and Tanzania.

Target group: Different parts of Tanzania where several micronutrient deficiencies coexist, for the use of children, women, and the whole family.

Vehicles: A fine orange-flavoured powder near white in colour that can be made into a fortified drink under field-testing in Tanzania.

The Company has already produced an iron-fortified, chocolate-flavoured mixture for addition to milk for use by iron-deficient children in Mexico. A similar chocolate powder mix fortified with iron, vitamin A, and iodine has also been produced for addition to milk and is currently under evaluation in the Philippines.

Fortificants: Iron, iodine, and vitamin A as well as other micronutrients.

Fortification level: When 25 g of orange-flavoured powder is added to 200 ml of water, it provides micronutrients at the following levels, vitamin A at 35% of RDA, iodine at 35% of RDA, iron at 35% of RDA, and vitamin C at 100% of RDA. The exact amounts of these micronutrients can be readily adapted to meet the recommendations of local experts.

Technology: Process and equipment: Ready-made premixes are produced by private companies for use by beverage manufacturers. Technologies for production of such premixes are usually not disclosed.

Status and results of field trials: Currently in process of being field-tested in Tanzania.

Product: The powder is near white and rapidly dissolves in water. The drink is orange coloured and is palatable. It is made for addition to water because milk is not widely used by rural children in Tanzania.

Quality aspects: The product can be stored for up to a year without significant deterioration.

Observations: It is suggested that this product be offered as a new approach to reducing micronutrient deficiencies in conjunction, but not in place, of other current strategies.

Future requirements/developments: Research into factors that determine success and reporting on successes in fortification programs implemented.

FORTIFICATION OF FOOD AID

The inadequacy of both quantity and quality of the food distributed to refugee populations has been widely documented. A typical refugee ration is composed of only a few commodities such as cereals, sugar, and oil. If refugees are unable to supplement their rations, they are prone to a variety of nutrient deficiencies.

Prolonged refugee feeding situations are specially prone to micronutrient deficiency problems. The development of xerophthalmia, iron deficiency anemia, scurvy, and pellagra among refugees in camps have been reported (Toole 1994).

In some specific cases, deficiency diseases have been controlled, at least intermittently, by supplying appropriate foodstuffs. Yet, to help prevent and alleviate such deficiencies from occurring, fortification of food aid has been suggested.

According to the recommendations of the International Conference on Nutrition (World Declaration and Plan of Action for

Nutrition 1992), donor countries and involved organizations must ensure that the nutrient content of emergency food aid for refugees and displaced persons should "meet the nutritional requirements, if necessary through fortification or ultimately through supplementation" (Para. 40m, p. 30.). Also, "governments, in collaboration with the international community, should provide sustainable assistance to giving high priority to the prevention of malnutrition, and the outbreak of micronutrient deficiency diseases" (Para. 37a, p. 26). Such fortification should include iodine; iron; vitamins A, B, and C; and other micronutrients depending on the local situations and risk of various deficiencies.

Potential vehicles for micronutrient addition are cereals, oil, pulses, salt, and, occasionally, sugar. Henry (1995) has identified the following opportunities for micronutrient additions to refugee foods:

Vehicle	*Fortificant*
Cereals	B vitamins, iron, calcium, and zinc
Oil	Vitamin A
Sugar	Iron and vitamin A

The possibility of using fortification of bulk food aid commodities to improve the quality of refugee rations is being explored by some donors. For instance, Canada and the US provide significant quantities of edible oil as food aid for many countries. These supplies can readily be fortified with vitamin A at source in the countries of origin. Fortification of processed cereals with vitamin A should be given priority, particularly if sufficient quantities of blended foods are not available. Iron and B-complex vitamins can be added to cereal flour. Whole grains should be provided to displaced people or refugees under emergency situations, only if centralized milling is available and in-country fortification is feasible. In such cases, uniform mixing of premixes with milled commodities should be ensured.

Where distribution and consumption can be more closely monitored, cereals are the most feasible vehicles for food fortification. In other situations, edible oils are good alternatives. For instance, in the Integrated Child Development Services (ICDS) feeding program in India, fortification of vegetable oils with vitamin A has been found to be more cost effective than fortification of a corn-soy blend (CSB) (Atwood et al. 1994). Shipment losses were reported to be 35% for CSB, but only 15% for oil. Also, addition of vitamin A to oil costs less than fortifying flour with vitamin A (OMNI 1994). This is because vitamin A is fat-soluble and is readily dispersed in oil and the cost of converting it to powder for addition to flour is saved.

In other situations as in Ecuador, however, oil is not consumed with blended foods at maternal and child health centres and, therefore, vitamin A-fortified blended foods should be made available. The choice between fortifying vegetable oil or blended foods with vitamin A would, therefore, depend on the particular needs of recipient countries.

When foodstuffs are provided in nonemergency food aid programs, e.g., food- for-work or supplementary feeding programs, they should be fortified with micronutrients that are known to be deficient in the population in question. In Guatemala, a biscuit made from the commodities provided by the WFP is distributed to 1.3 million primary school students every day. Using technology developed by the Institute of Nutrition in Central America and Panama (INCAP), the biscuit is fortified with vitamin A, some B vitamins, iron, and iodine. In Malawi, a food fortification plant, has been established to produce fortified maize meal for both refugee and domestic populations. The WFP reports distribution of iodized salt, vitamin A-fortified skim milk, and vitamin- and mineral-fortified cereal-legume blends in some countries with populations at risk of these deficiencies.

Food aid will be required on an increasing scale during the 1990s both as emergency nutrition intervention and when indigenous food supplies are limited. There is a definite need for a new blended food, produced specifically for relief programs and nutrition rehabilitation centres. In many refugee feeding situations, blended foods are included in the ration for their micronutrient content. Both WFP and UNHCR have taken action to include blended foods in the general refugee ration (WFP/UNHCR 1994).

There are several types of blended foods available, most of which have been designed as a supplement to the available local diet to target the young children and pregnant women as well as refugees and displaced people. The composition of some existing/proposed blended foods has been summarized by Beaton (1995). The Milk Marketing Board, UK, has recently produced an instant blended food (IBF) that has been tested for acceptability by six NGOs operating nutrition programs in Rohingya, Bangladesh, with reported successful results. This product requires no cooking and has good storage and handling properties. IBF is fortified with vitamin A, iron, and iodine along with some other micronutrients. The question is whether a universal blend can be designed for use in different feeding programs or whether different blends will be necessary for specific applications.

Recently, the Canadian International Development Agency (CIDA) commissioned a study to develop specifications for a micronutrient premix to be added in circumstances where blended foods are intended for general distribution. The final report of the study (Beaton, August 1995) has identified three distinct options to fortification of the general diet of refugees (Table 8-6):

- Centralized fortification of the staple cereals,
- Community level fortification of cereals, and

Table 8-6. Some possible fortification points: Advantages and disadvantages.

Level of fortification	*Effectiveness*	*Special considerations*
National or regional milling and fortification	Likely to be most efficient and effective	Presents increased handling and shipping costs. The shortened shelf life of milled cereal more likely to be a problem.
Milling and/or fortification of milled community level (BEFORE DISTRIBUTION)	Very likely to be effective. Used soon enough that shelf life not problematic	Increased difficulty of quality control cereal at many facilities. Need equipment and training.
Grinding and fortification at household level (AFTER DISTRIBUTION OF WHOLE GRAIN CEREAL)	Less likely to be effective (but likely to be better than present blended foods). Recognizes the reality of the existing system .	Requires substantial education component. Effectiveness depends upon conscious action by individuals.

Table 8-7. Interim specification for a cereal fortification premix for refugees in Africa (applicable to maize-, wheat-, and sorghum-based rations).

Nutrient to be added		*Proposed source*		
Nutrient	In 1900 kcal ration	Suggested source	Proportion active (%)	Amount per kg premix
Vit A	960 *ug*[a]	Encapsulated retinyl Palmitate	75%	0.750 g
Vit D	10 *ug*	Commercial food grade source	0.25%	2.343 g
Vit C	110 mg[a]	Coated ascorbic acid	97.5%	66.08 g
Vit B_{12}	1.5 *ug*[a]	Commercial food grade source	1%	0.088 g
Folate	0.3 mg	–	100%	0.176 g
Riboflavin	0.84 mg	–	100%	0.492 g
Niacin	6.5 mg	Nicotinamide form	100%	3.807 g
Pantothenate	1.7 mg	–	100%	0.996 g
Calcium	570 mg	Calcium carbonate	40%	843.6 g
Iodine[b]	–	–	–	–
Iron	8 mg	NaFeEDTA	13%	36 g
Selenium	15 *ug*	–	100%	0.0087 g
Zinc	18 mg	Zinc sulphate	23%	45.94 g

Note: This premix is based on estimated normative nutrient requirements. It would be used at a rate of 4.22 kg/ MT of maize.
[a]Includes provision for a 25% loss during storage (added level is 33% over target).
[b]Iodine not included on basis of assurance that WFP distributes iodized salt; if uncertain, add potassium iodate.

- Household-level fortification using a multiple-fortified premix.

All three approaches mentioned in the foregoing would make use of the same fortification premix, but the degree of dilution and dispensation would differ in each case.The report contains interim specification for a cereal fortification premix for refugees in Africa (Table 8-7).

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9. IMPLEMENTATION ISSUES AND RESEARCH NEEDS

IMPLEMENTATION ISSUES

With a few notable exceptions, national programs for micronutrient fortification of food have not as yet been implemented in developing countries or have not been very successful. There are a number of constraints that jeopardize the success of a fortification program. Identification of such constraints is an urgent priority:

- Inadequate awareness among both government and industry of the extent and severity of micronutrient deficiencies and, hence, lack of commitment for their elimination;
- Need for, and role of, food fortification is not clearly defined;
- Barriers to technology transfer;
- Limited choice of suitable vehicles;
- Nonexistent or ineffective monitoring and evaluation systems;
- Price differences between fortified and unfortified foods. This often leads to lack of demand for fortified products;
- Legislation mandating food fortification to add a measure of compulsion not enacted or, where in place, inadequately enforced;
- Lack of logo or seal of approval; and
- Weak coordination and linkage between the health and industry sectors.

Key issues to be considered are:

- Although considerable progress has been made in initiating and streamlining control programs in several countries, logistic problems and bottlenecks do remain. The challenge is to identify and tackle these constraints systematically at the regional and country level through effective advocacy, coordination, and monitoring. Research is needed into factors that determine success. The successes of fortification programs in execution need to be reported, e.g., reporting on successful salt iodization, vitamin-fortified sugar, or iron-fortified cereal could provide valuable lessons to be used in planning strategies for the other micronutrient fortification programs. Similary, reasons for program failures should be identified and carefully evaluated.
- Research and development efforts have enhanced effectiveness of fortification technology. In spite of these development efforts, a large gap between knowledge and application of fortification technologies still exists. In certain cases, the technology still needs to be refined and/or tested for product stability, absorption, and consumer acceptability before it can be applied on a large scale. Micronutrient utilization from the fortified foods also needs to be carefully evaluated. Often the technology that is already developed is not available to countries that need it most.
- In many countries, the choice of appropriate vehicles that are widely and consistently consumed by the populations at risk is limited. Local dietary habits should be taken into account. The identification of such foods, including condiments and snack foods and their consumption patterns, is an urgent priority. Fortified foods that have proven to be viable in a controlled environment should be considered in countries where consumption levels of the food vehicle are known.
- From a nutritional and economic point of view, the search for suitable micronutrient multimixes, incorporated in suitable food vehicles, should be supported. To reduce the cost of fortification, fortificant production at a national or regional level should be explored.

RESEARCH NEEDS

Research needs specific to each of the three micronutrients are discussed below.

Iodine: In the case of iodine, problems yet to be resolved relate mainly to the stability of the added compound under different storage and cooking conditions. The stability of iodine compounds in salt can be significantly improved by better refining procedures and packaging. Applications for fortification of fish sauce, soya sauces, pickled preserves, salted preserves, fish curing, meat curing etc., with iodized salt should be investigated.

Field research is needed to solve the problem of low retention of iodine, e.g., losses of iodine during handling, transport, and storage, including in-house iodine losses. Another field that could be investigated is the use of iodine (or iodized salt) in oral rehydration salts.

Iron: Cereals are the major staple foods consumed by many of the poorer populations of the world. Iron in cereal-based vegetarian diets is poorly absorbed and, in consequence, nutritional iron deficiency is prevalent. Many constraints need to be overcome for fortification of such diets with iron because the potential vehicles are not centrally processed and the iron compounds react with several food ingredients.

The buff-coloured, insoluble iron phosphate compounds are stable under a variety of storage conditions but are poorly absorbed. Addition of ascorbic acid has proven to be a suitable way to improve iron bioavailability. The soluble iron salts like ferrous sulphate are well absorbed but could easily produce discolouration through reacting with other food ingredients. Stabilizers have been added along with the iron compound to retain it in an absorbable form, and the structure of certain iron compounds has been modified to improve absorption.

Research should be focused on the identification of a form of iron that is adequately absorbed and yet does not alter the appearance or taste of the food vehicle selected. The rapid and simple stearine microencapsulation method as used to fortify cheese with iron may be a suitable technology to allow iron fortification of other dairy products and foods with high fat and moisture content.

Vitamin A: Currently, some experimental work has been undertaken to retard the loss of potency of vitamin A-fortified foods on storage. Field research is needed into the problem of stability of the added compound under different storage and cooking conditions.

More attention should be given to locally available sources of vitamin A for fortifying meals. ß-Carotene is a good fortificant with very little toxicity limitations. When vitamin A-rich fruits and vegetables are seasonally available and are in excess, improved technologies are required for their preservation for later use in foods as condiments, flavourants, and colourants.

The refining of red palm oil without significant loss of ß-carotene has been a recent breakthrough. This technology needs to be adopted by all palm oil refineries.

Overall some knowledge gaps in food fortification are:

- Simple semiquantitative assay to measure iron and vitamin A in foods.
- Simple feeding and mixing equipment for powder fortification.
- Type of iron sources as related to compatibility and bioavailability in different diets.
- Organoleptic properties of the products made from fortifying foods.
- Stability of vitamin A and iron, under a variety of storage and processing conditions.
- Stability and interaction between iron and vitamin C in bread.
- Safety data for some iron sources, e.g., FeEDTA.

Further research/knowledge in the following areas would aid program implementation:

- Standard for fortification (minimum requirement).
- Standards for quality assurance and monitoring for: simple semiquantitive assay system and sampling and date analysis procedures.
- Selection and specification of simple mixing/feeding equipment (large and small scale).
- Develop technology to improve vit A/iodine stability and interaction with iron (e.g., antioxidant).
- Development of a computer model to project bioavailability of different iron sources.

RECOMMENDATIONS

The global control of micronutrient deficiencies is a realizable goal, notwithstanding the magnitude of the task and the many challenges and constraints that remain to be resolved. The development of successful programs for micronutrient fortification of foods calls for active collaboration between several sectors: the scientific community, national and local governments, NGOs, private industry, media, consumer groups, and donor agencies.

The scientific community will need to develop and provide workable technologies that can be implemented in the developing countries. National and local governments must have the political will, provide the administrative support, and prescribe the framework within which the solutions can be implemented and regulated. Private industry needs to be motivated to become an active partner in this effort recognizing the economic and social benefits that it could derive. The media should be used to educate the population on the problems of micronutrient malnutrition and on the importance and safety of fortified foods. The consumer should be educated regarding the benefits and low cost of fortified foods to create a "demand pull" to which industry will have to respond. International and bilateral aid agencies could provide the link and the coordination between the different sectors to implement the programs and make them self-supporting and sustainable.

The following recommendations are made with a view to identifying and promoting opportunities for food fortification as an important component of the strategies to eliminate micronutrient malnutrition:

- Food fortification is a unique example where industry and trade, working in a largely commercial enviroment, are required to participate and play a leading role in a health intervention endeavour. To have an effective and sustainable fortification program, it is vital that the health and industry sectors work in close collaboration and explicitly understand and recognize each other's viewpoints, concerns, and interests.
- The food fortification strategy should be linked with other intervention strategies like supplementation and nutrition education.

- The establishment and sustenance of an effective micronutrient delivery system calls for a multisectoral effort that will involve relevant sectors like government, industry, and consumer groups in planning and implementation. The food industry should be motivated to comply and penalties should be enforced for noncompliance.
- A detailed, technical, problem-solving exercise should be carried out to confirm that the fortification process is feasible and does not alter the vehicle in any way and that nutrient losses on storage and cooking are within tolerable limits. Industry should be involved in technology development, production, and quality control. Companies with R&D facilities could provide a rich source of technical expertise. International expert groups on iodine, iron, and vitamin A issues need to take the lead.
- There is a need to coordinate development of multiple fortification programs. Technology is now available to a limited extent, and more extensive and coordinated research and development is needed. Technology development will have to be followed up with field trials and pilot commercial trials to evaluate the technoeconomic feasibility and consumer acceptability of the product. There should be a mechanism for transfer of technology from available sources to countries/companies that need them.
- Fortification programs should be planned to dovetail into existing food-production and distribution systems within a country or region with minimum disruption and cost. Mechanisms like subsidies need to be identified to reduce costs to consumers. Such costs are marginal for iodine and vitamin A but become more significant for iron.
- Food quality should be regulated through legislation and effectively enforced. In countries where there is no political will, food adulteration is common and consumers accept tampering as the norm, it may be difficult to enforce legislation. Consumer unions can play an important role in ensuring that the food sector complies with food legislation by informing the consumers about the importance of fortification and lobbying the government and food industry to fortify food.
- The importance of social communication cannot be overstressed. All available media should be used to educate the population on the problems of micronutrient malnutrition and on the importance and safety of fortified foods. Consumers should be educated to demand a better product and be ready to pay a slightly higher price for that product.
- Regardless of external input, nothing can succeed without an adequate nucleus of well-trained people. Specialized training is especially called for in the assessment, fortification, quality control, and monitoring/evaluation procedures.
- As programs get under way, effective monitoring of process and outcome variables is critical. Measurement of food quality and fortificant levels in the foods at different levels from production to consumption is an essential step to ensure that adequate quantities of the nutrient are reaching the population. This must be combined with periodic estimation of clinical and biochemical indicators to evaluate the impact of the intervention. Programs should be envisioned as long term with evaluation as an essential component to identify progress, problems, and needs.
- Intersectoral and international mechanisms of cooperation and coordination should be established to control distribution and marketing of fortified foods. In Sub-Saharan Africa, regional initiatives have been developed to iodize salt at the production source so that all recipient countries will benefit. A similar initiative may be called for to ensure that all wheat flour, dry skimmed milk powder, salt, and processed foods exported to the developing countries is fortified with micronutrients at a level that the importing country may specify.

APPENDIX 1

POTASSIUM IODATE PRODUCERS AND QUALITY SPECIFICATION

PRODUCTION OF POTASSIUM IODATE

The major iodine producers are Japan and Chile. Many manufacturers produce and supply potassium iodate, both in developed and in developing countries. Some of them are:

- INQUIM (Chile)
- Helm (Hamburg, Germany)
- ACF Chemie (Maarssen, The Netherlands)
- William Blythe Ltd (Lancashire, UK)
- MBI Chemicals (Madras, India)

UNICEF's Supply Division based in Copenhagen, Denmark, has entered into a long-term arrangement with INQUIM. The product is packaged in new fibre drums with a sealed, heavy-duty polyethylene bag of 50 kg net and is available at US$7.70/kg FOB Valparaiso (in 1995 prices).

Potassium iodate is produced by the electrochemical reaction of iodine with potassium hydroxide. The chemical reaction equation is: $3\ I_2 + 6\ KOH \rightarrow KIO_3 + 5\ KI + 3\ H_2O$. The process involves dissolving iodine in caustic potash solution and subjecting the solution to electrolysis, using suitable electrodes. About 80% of KIO_3 crystallizes from the reaction mixture, which is separated. One kg of iodine will yield 1.55 kg of potassium iodate. The process know-how can be obtained from the National Research Development Corporation of India, New Delhi.

QUALITY SPECIFICATIONS FOR POTASSIUM IODATE

The specifications of the "standard" potassium iodate are listed in the following and conform to the Food Chemical Codex (FCC):

QUALITY SPECIFICATIONS FOR POTASSIUM IODATE

1. Physical appearance	- (Almost) white crystalline powder
2. Particles retained on 100 mesh B.S. sieve	- Max 5% (w/w)
3. Solubility	- Soluble in 30 parts water
4. Reaction	- A 5% solution in water shall be neutral to litmus
5. Iodine	- Max 0.005% (w/w)
6. Sulphate	- Max 0.02% (w/w)
7. Heavy metals (as Pb)	- Max 20 ppm
8. Iron	- Max 10 ppm
9. Bromate, bromide, chloride and chlorate	- Max 0.5% (w/w)
10. Insoluble matter	- Max 0.5% (w/w)
11. Loss on drying at 105°C	- Max 0.5% (w/w)
12. Assay	- Min 99% potassium iodate (dry base)
13. Packaging	- Plastic bag or paper drums with closed seal (50 kg)

Source: Mannar and Dunn (1995). See p. 76 for full reference.

APPENDIX 2

A. COMMERCIALLY AVAILABLE IRON COMPOUNDS AND THEIR RELATIVE COSTS

Commercially available iron compounds	*Characterisitics*				*Food vehicles*[c]				
	% iron content	Bioavailability[a] cost		Relative factor[b]	Cereal	Salt	Sugar food	Infant age (milk)	Bever-
		Human	Animal						
Freely water soluble									
Ferrous sulphate	20	1	1	5.0	±	+	+	+	+
Ferrous gluconate	12	1	1	8.3	±	+	+	+	+
Ferrous lactate	19	1	1	5.3	n/a	–	–	±	+
Ferric ammonium citrate	18	1	1	5.5	±	–	–	+	±
Ferrous ammonium sulphate	14	n/a	1	–	n/a	n/a	n/a	n/a	n/a
Ferric choline citrate	14	n/a	1	–	n/a	–	–	n/a	n/a
Slowly soluble									
Dried ferrous sulphate	33	1	1	3.0	±	±	+	±	+
Ferric glycerophosphate	15	1	1	6.6	±	–	–	±	±
Ferric citrate	17	3	2	17.6	±	±	+	±	+
Ferric sulphate	22	3	1	13.6	–	–	–	–	–
Ferric saccharate	35	2	1	6.6	+	n/a	n/a	n/a	+
Ferric chloride	34	2	1		–	–	–	–	–
Poorly soluble									
Ferrous fumarate	33	1	1	3.0	+	+	–	–	–
Ferrous succinate	35	1	1	2.8	+	n/a	–	–	–
Ferrous tartrate	22	2	2	9.0	n/a	n/a	n/a	n/a	n/a
Ferrous citrate	24	2	2	8.4	±	±	n/a	±	+
(Almost) insoluble									
Ferric pyrophosphate	25	3	3	12.0	+	+	+	–	–
Ferric orthophosphate	28	3	3	10.7	+	+	+	–	±
Sodium iron pyrophosphate	15	3	3	20.0	–	–	–	–	–
Reduced elemental iron:									
- by hydrogen (10–45 μm)	96	2	2	2.1	±	–	–	–	–
- by carbon monoxide	96	2	2	2.1	±	–	–	–	–
- carbonyl iron	98	2	2	2.1	±	–	–	–	–
- by electrolysis (–20 μm)	97	2	2	2.1	±	–	–	–	–
Ferric oxide	70	3	3	4.2	–	–	–	–	–
Ferric hydroxide	62	3	3	4.8	–	–	–	–	–
Ferrous carbonate	35	3	3	8.5	–	–	–	–	–
Iron complex compounds									
Sodium ferric EDTA	13	1	1	7.7	+	n/a	+	±	±

[a]Rating: 1 = good; 2 = fair; 3 = poor; n/a = info not available.
[b]Relative cost factor for humans =[(Bioavailability x 100)÷ % iron content]. Equivalent cost on bioavailability basis = [relative cost factor for compound x price/kg of iron compound].
[c]Vehicles: + = recommended; ± = variable; – = not recommended; n/a = info not available.
Source: Adapted from INACG (1990). See p. 23 for full reference.

B. RELATIVE COSTS OF COMMONLY USED IRON SOURCES

Iron source	*Cost (US $/kg)*	*Iron content (%)*	*Cost of iron (US $/kg of Fe)*
Ferrous sulphate, dried	1.43	32.1	4.45
Hydrogen-reduced	1.06	97.2	1.09
Electrolytically reduced	3.20	98.2	3.26
Carbonyl-reduced	6.37	98.0	6.50
Ferric orthophosphate	1.70	28.6	5.94
Sodium iron pyrophosphate	1.94	15.7	12.36
Ferrous fumarate	3.28	33.0	9.95

Source: Bauernfeind and Lachance (1991). See p. 23 for full reference.

APPENDIX 3

COMMERCIALLY AVAILABLE VITAMIN A AND CAROTENOIDS IN FOOD FORTIFICATION

A. VITAMIN A USED IN FOOD FORTIFICATION.

Type and name	*Potency (millions of IU/g)*	*Other ingredients*	*Usage*
LIQUID PRODUCTS			
Vit. A palmitate	1.65–1.8	Edible antioxidant; no oil diluent	Where maximum concentration is required; with stabilizers
Vit. A palmitate	1.65–1.8 no oil diluent	No antioxidant;	Where maximum concentration is required; with stabilizers
Vit. A palmitate Type PIMO/BH)	1.0	Edible oil; edible antioxidant	Recommended for general use; with stabilizers
Vit. A acetate or -palmitate	1.0	Edible oil diluent; no antioxidant	For specific uses
Vit. A palmitate emulsion	0.5	Emulsifiers; antioxidants; preservative	Fortification of cereals, milk products, potato flakes and products that require specific processing techniques
DRY PRODUCTS			
Vit. A palmitate beadlets, Type 500	0.5	Gelatin; carbohydrate; tricalcium phosphate; antioxidant; preservative	For products not dispersed in cold water where high resistance to moisture and heat required, e.g. extruded foods
Vit. A palmitate beadlets, Type 250-CWS	0.25	Gum acacia; carbohydrates; modified food starch; antioxidants	Water dispersable; for dry products to be reconstituted before use, e.g. sugar
Vit. A palmitate beadlets, Type 250-S	0.25	Gelatin; dextrose; modified food starch; coconut oil; sorbitol; sodium citrate; antioxidants	Water dispersable; free flowing beadlets to help meet the stringent flavour needs of milk based products and other beverages
Vit. A palmitate beadlets, Type 250-T	0.25	Acacia; carbohydrate; modified starch; alpha-tocopherol; preservative	Water dispersable fine beadlet product for premixes
Vit. A palmitate Type 250-SD	0.25	Acacia; lactose; coconut oil; preservatives	For product use where very fine particle size is desired, i.e. maize flour, vitamin premixes, dry milk, sugar, beverage powders

Source: Bauernfeind and Arroyave (1986). See p. 23 for full reference.

B. SOME APPLICATIONS OF CAROTENOIDS AS VITAMIN A PRECURSORS

Type	Description	Uses	Solution
30% ß-carotene liquid suspension	Micronized ß-carotene suspension in food-grade vegetable oil; pourable at > 24°C; semisolid at 4-16°C; no anti-oxidants; dissolves readily in warm oil	Colouring fat and oil products, margarine, process cheese, frozen and dried egg yolk, winter butter and other fat-base products	1.5 g of suspension to 450 ml
24% ß-carotene semisolid suspension	Micronized ß-carotene in hydrogenated vegetable oil; pourable at > 38°C; semisolid at 21-32°C; no antioxidants; dissolves readily in warm oil	Colouring fat and oil products, margarine and other fat-base products	2 g of suspension to 480 ml warm vegetable oil; stirring to dissolve. 1 ml = 1 mg ß-carotene
22% ß-carotene HS liquid suspension	Micronized ß-carotene in food-grade vegetable oil; pourable at > 24°C; semisolid at 4-16°C; stabilized with anti-oxidants; dissolves readily in warm oil	Colouring popping oil, heat-stressed cooking oils, fat-base products where greater carotene stability is required	2 g of suspension to 440 ml warm vegetable oil; stirring to dissolve. 1 ml = 1 mg ß-carotene
3.6% ß-carotene liquid emulsion	ß-carotene in orange oil and brominated vegetable oil emulsified in a hydrolysed protein base; pourable at 24°C; specific gravity, oil phase 1.053 ± 0.003 (12.5–13.6° Brix); stabilized with antioxidants	Especially designed for colouring orange-flavoured drinks and fruit juices blends; adjusted for specific gravity in clear glass or opaque container	3 g of emulsion to 108 mls water; stirring to disperse. 1 ml = 1 mg ß-carotene
Dry ß-carotene beadlets 10%	Colloid ß-carotene in a gelatin-carbohydrate matrix; stabilized with antioxidants; readily dispersible, with stirring in warm water (54°C) water	Colouring water-based foods and beverages for dry products to be reconstituted in warm	1 g of beadlets of 96 ml of warm water; stirring to disperse. 1 ml = 1 mg ß-carotene
Dry ß-carotene beadlets 2.4%	ß-carotene in vegetable oil emulsified in a gelatin-carbohydrate matrix; stabilized with antioxidants; readily dispersible in water (24°C)	Colouring juice drinks, dry beverage bases, beverages and other water-base liquid or dry foods to be reconstituted in water	4 g of beadlets of 100 ml of warm water; stirring to disperse. 1 ml = 1 mg ß-carotene
Dry ß-carotene powder 1% CWS	ß-carotene in dry powder form; in dextrin, acacia carbohydrate; ascorbate + tocopherol as anti-oxidants; readily dispersible in water	Colouring dairy products, baked goods, sauces, icing, puddings etc	10 g of powder to 100 ml of warm water; stirring to disperse. 1 ml = 1 mg ß-carotene
ß-carotene blend with vit A (and D)	Micronized ß-carotene suspension in vegetable oil; with dissolved vit A+D	Simultaneous colouring and vitamin A fortification of margarine, mellorine, etc.	
20% Apo-carotenal liquid suspension	Micronized suspension in food graded vegetable oil; pourable at 24°C; no added antioxidants; semisolid at 4-16°C; dissolves readily in warm oil;	Colouring fat and oil products, salad dressing, processed cheese and other fat-base foods	1 g of suspension to 200 ml warm vegetable oil; stirring to disperse. 1 ml = 1 mg apo-carotenal
Apo-carotenal solution 2%	Apo-carotenal (1.4%) + ß-carotene (0.6%) dissolved in a food-grade modified vegetable oil composition;	Colouring process cheese, salad dressings and other fat-base foods	5 g of solution to 100 ml of vegetable oil; stirring to dilute 1 ml = 1 mg apo-carotenal
Apo-carotenal solution #73	Apo-carotenal + ß-carotene dissolvedin a food-grade modified vegetable oil composition; stabilized with antioxidant	Colouring process cheese, salad dressings and other fat-base foods	5 g of solution to 100 ml of vegetable oil, stirring to dilute 1 ml = 0.7 mg apo-carotenal + 0.3 mg ß-carotene
Apo-carotenal solution 4%	Apo-carotenal dissolved in a food-grade modified vegetable oil composition with α-tocopherol	Colouring process cheese, salad dressings and other fat-base foods; dry spice & bread mixes	5 g of solution to 200 ml of vegetable oil, stirring to dilute. 1 ml = 1 mg apo-carotenal

Source: Adapted from Klaeui and Bauernfeind (1981).

APPENDIX 4

COMPOSITION OF SOME FORTIFICATION PREMIXES PRODUCED BY DIFFERENT MANUFACTURERS

Atochem N-richment-A cereal fortification premixes (fortification level per kg flour).

Vehicle Nutrient	Maize/Sorghum	Wheat flour	Bulgur wheat[a]
Thiamine (vit B_1)	4.9 mg	5.7 mg	3.3 mg
Riboflavin (vit B_2)	2.6 mg	4.0 mg	2.2 mg
Niacin	31 mg	46 mg	–
Iron	26 mg	37 mg	11 mg
Vitamin A	2,340 IU	2,340 IU	2,340 IU

[a] Parched, crushed wheat as prepared and used as a dietary staple in Turkey and some other countries.

Roche rovifarin 955 fortification premix.

Micronutrient	Dosage per kg flour
Thiamine (vitamin B_1)	4.45 mg
Riboflavin (vitamin B_2)	2.65 mg
Niacin	35.62 mg
Iron	29.28 mg

Roche precision premix.

Nutrient	Dosage (mg/kg flour)
Vitamin A 250 SD	24.00
Iron electrolyte	19.10
Potassium iodide	243.00
Ascorbic acid F.P.	78.00
Niacinamide	22.00
Pyridoxine hydrochloride	2.78
Riboflavin, type S	1.96
Thiamine mononitrate	1.73
Vitamin B_{12} 1% SD	0.70
Vitamin E 50% CWS/F	69.00
Vitamin D_3 100 SD	4.80
Folic acid	0.48
D-calcium pantothenate SD	12.54
Biotin	0.36
Di-cal phosphate anhydrous	0.00
Copper gluconate	15.70
Zinc oxide	20.00

APPENDIX 5

ACRONYMS AND ABBREVIATIONS

AACC	American Association of Cereal Chemists
AAP	American Academy of Paediatrics
AAS	Atomic absorption spectrophotometer
AMA	American Medical Association
ARS	Agricultural Research Service (USDA)
BDN	Bon Dente Nutrition, Inc.
BHC	Bovine Haemoglobin Concentrate
BMIG	Bristol-Myers International Group
CAR	Central African Republic
CCP	Critical Control Point
CDNHW	Canadian Department of National Health and Welfare
CESNI	Centre of Studies on Infant Nutrition
CFN	Council of Food and Nutrition (AMA)
CFOP	Complex Ferric Ortho-Phosphate (microcrystalline)
CFTRI	Central Food Technological Research Institute
CHNO	Centre Horticole et Nutritionnel de Ouando
CIDA	Canadian International Development Agency
CMAFP	Committee on Medical Aspects of Food Policy
CN	Committee on Nutrition (AAP)
CONICET	Consejo Nacional de Investigaciones Cientificas y Tecnicas
CPS	Canadian Paediatric Society
CPHIIF	Chilean Public Health Institute for Infant Foods
CSRS	Cooperative Research Service (USDA)
CSM	Corn-Soyabean-Milk mixture
CT	Champion Trust
CWS	Cold Water Soluble
DGIS	Dutch Directorate General International Development Cooperation
EC	European Community
EDTA	Ethylene-Diamine-Tetraacetic Acid
ENI	Ethiopian Nutrition Institute
ESPGAN	Society for Pediatric Gastroenterology and Nutrition
FAO	Food and Agriculture Organization
FCC	Food Chemical Codex
FCR	Foundation for Chemical Research
FD	Food Diversification
FDA	US Food and Drug Administration
FF	Food Fortification
FFWF	Fonds zur Forderung der Wissenschaftlichen Forshung
FIIRO	Federal Institute of Industrial Research, Oshodi
FNRCC	Philippine National Rice and Corn Corporation
FNRI	Philippine Food and Nutrition Institute
FPR	Foundation for Pediatric Research
GMP	Good Manufacturing Practices
HIC	Haem Iron Concentrate
HNI	Human Nutrition Institute
HPLC	High pressure liquid chromatography
HPB	Health Protection Board (CDNHW)
IAC	International Agricultural Centre
IAEA	International Atomic Energy Agency
ICCIDD	International Council for the Control of IDD
IDA	Iron Deficiency Anemia
IDD	Iodine Deficiency Disorders
IDRC	International Development Research Centre
ILO	International Labour Organization
ILSI	International Life Science Institute
INACG	International Nutritional Anaemia Consultative Group
INCAP	Nutrition Institute of Central America and Panama
INTA	Chilean Public Health Institute for Infant Foods
IVACG	International Vitamin A Consultative Group
IU	International Unit
JECFA	Joint FAO/WHO Expert Committee on Food Additives
KIT	Royal Tropical Institute
MFP	Multi Purpose Food
MI	Micronutrient Initiative
MJNG	Mead Johnson Nutritional Group
MM	Micronutrient Malnutrition
MOH	Ministry of Health
MOHW	Ministry of Health and Welfare
MRC	Medical Research Council
MSG	Monosodium Glutamate ($C_5H_8NO_4.Na.H_2O$)
MSI	Mineral Safety Index
NAS	National Academy of Sciences
NDC	US National Dairy Council
NGO	Nongovernmental organization
NIH	US National Institutes of Health
NIN	National Institute of Nutrition
NNRGP	Nestlé Nutrition Research Grant Programme
NOVIB	Netherlands Organization for International Development Cooperation
NRC	US National Research Council
ORS	Oral Rehydration Salt
PAG	Protein Advisory Group
PAMM	Programme Against Micronutrient Malnutrition
PATH	Program for Appropriate Technology in Health
PHC	Primary Health Care
PHS	US Public Health Service
PPM	Parts per million
QA	Quality assurance
QC	Quality control

RCL	Ricegrowers' Co-operative Limited
RDI	Recommended Dietary Intake
RE	Retinol Equivalent
SAAEB	South African Atomic Energy Board
SARCDC	Swedish Agency for Research Cooperation with Developing Countries
SASA	South African Sugar Association
SD	Spray Dried
SCFAR	Swedish Council for Forestry and Agricultural Research
SECYT	Argentina Secretaria de Ciencia y Tecnica
TFNC	Tanzania Food and Nutrition Centre
TOOL	Transfer of Technology for Development
TQM	Total quality management
UBACYT	Universidad de Buenos Aires
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UNU	United Nations University
USAID	US Agency for International Development
USDA	US Department of Agriculture
USP	US Pharmacopea
VAD	Vitamin A deficiency
WFP	World Food Programme
WHO	World Health Organization
WIC	Women, Infants and Children programme
WPC	Wheat-Protein Concentrate
WSD	Whey-Soya Drink
WT	Welcome Trust

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